ASTRONAUT ZERO GRAVITY PERFORMANCE EVALUATION PROGRAM

FINAL STUDY REPORT

Volume I

Summary Technical Report

PREPARED UNDER
CONTRACT NUMBER NAS 9-8640

FOR

MANNED SPACECRAFT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HOUSTON, TEXAS 77058

GENERAL ELECTRIC

NASA CR 108569

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PREFACE

The final report on the Astronaut Worksite Performance Program for the development of Experiment M508 is presented in three volumes. The volume designations are:

Volume	Title
I	Summary Technical Report
II	Detailed Technical Report
III	Handbook of Human Engineering Design Data for Reduced Gravity Conditions

The analytical, design, manufacturing and certain ground based zero gravity simulation portions of the program were performed by the Space Systems Organization of the General Electric Company Space Division.

In addition, considerable support was provided at the Manned Spacecraft Center, Marshall Space Flight Center and the Aeronautical Systems Division at Wright-Patterson Air Force Base. We would like to acknowledge those personnel who provided this support.

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SECTION 1

INTRODUCTION

The purpose of this final study report is to present the results of the work performed under Contract NAS9-8640, "Astronaut Zero Gravity Performance Evaluation Program". The program was performed during the period July 1968 through February 1970 and encompassed:

a. The definition and preliminary design of Experiment M508, EVA and IVA Hardware Evaluation, concerned with astronaut worksite performance evaluation.

b. The construction of two prototype models of the M508 Task Panel to verify design concepts, develop manufacturing procedures and to collect simulated astronaut worksite performance data.

c. The conduct of Experiment M508 using various ground based zero-gravity simulation modes.

d. The collection of additional data on man's force emission capability to establish 1-g and zero-g baselines.

e. The preparation and publication of a Handbook of Human Engineering Design Data for Reduced Gravity Conditions.

The Astronaut Zero Gravity Performance Evaluation Program was designed to fill a gap in our knowledge of man's capabilities to perform complex tasks in the zero-gravity environment. The resultant experimental program involved an evaluation of the major facets of astronaut performance while restricted to a limited work-site area. The program involved evaluation of the efforts required to install and enter different restraint concepts, remove panels and covers assoicated with gaining access to a work area, performance of specific tasks designed to evaluate the interactions between basic psychomotor behaviors and the parameters of the EVA/IVA, zero-gravity environment and equipment.

The total program efforts and results are summarized in Volume I, Summary Report and presented in detail in Volume II, Detailed Technical Report. Volume III consists of the Handbook of Human Engineering Design Data for Reduced Gravity Conditions and is an entirely independent document suitable for distribution by NASA as a basic handbook.

SECTION 2

PROGRAM SCOPE

This program was designed to broaden the knowledge base concerning man's ability to perform useful work in a zero-gravity environment. The approach in the attainment of this goal involved a three-pronged effort. The first element involved the definition, preliminary design and conduct of Experiment M508, an experimental program to provide data on astronaut orbital EVA and IVA worksite performance capability and support hardware. The objectives of this experiment were to provide:

a. Correlation of ground-based simulation with in-flight conditions.

b. Quantitative human worksite performance capability under zero gravity conditions.

c. Comparative evaluation of IVA/EVA restraints, tools, and pressure suits.

The second element involved the conduct of an experiment for the collection of one-g baseline and zero-g shirtsleeve force emission data through the use of neutral buoyancy simulation techniques. This provides data to supplement those available from the force-emission experiment (Experiment 84) conducted under Contract NAS8-18117 for the NASA/MSFC.

The third element involved the continuation and completion of the handbook also initiated under Contract NAS8-18117. This Handbook of Human Engineering Design Data for Reduced Gravity Conditions provides available subgravity performance data to the designers of spacecraft and was also used as input data for the experiment definition and system design effort above.

The scope and rationale of Experiment M508 merits further consideration and is adequately described in the early experiment definition and implementation plans that are quoted below:

> "The most important end objective will be that associated with the comparison between the results of flight and simulation tests, because simulations are the most productive sources of information available to guide the design work required for future missions. Practically any specific task can be simulated, and thus, the most fruitful human engineering experiments for the near future will be ones that help to establish how the results of simulations relate to experience in actual free flight. The value of the limited amount of experimentation that can be performed in the AAP mission will be multiplied many fold if the results yield generally applicable conclusions on how to conduct and analyze simulations to obtain valid information about how to work efficiently and safely in space. Therefore, the tests selected for the M508 Experiment are ones that are expected to reveal general relations between tests in real and simulated weightlessness, rather than faithful imitations of anticipated operational tasks."

Experiment M508 is comprised of a sequence of four basic human engineering tasks designed to measure man's capabilities for force exertion, eye-hand coordination and manual dexterity in an EVA and IVA environment.

The task sequence designed for this experiment is based on an operational analysis of 16 fundamental EVA experiments which were distilled from an entire spectrum of actual and predicted extravehicular activities. All of the important basic operations identified by the analysis have been included in the M508 task sequence, although it does not closely approximate any of the experiments suggested in the study.

With the four basic tasks configured into a single task panel, two subjects each performed the complete task sequence twice under six experimental conditions: three suit conditions (shirtsleeves, and operational and developmental pressure suits) and three modes of physical restraint. The tasks were suitably instrumented to record quantitative data on forces, torques, accuracy, etc., for each of four simulation modes, including 1-G, Neutral Buoyancy, KC-135 Zero-G aircraft and 6 DOF mechanical simulator.

SECTION 3

EXPERIMENT DEFINITION AND TASK SEQUENCE DEVELOPMENT

The first task of the Astronaut Performance Program was the generation of an experimental task sequence which would measure and yield data on manned performance capabilities in a zero-gravity environment. It was furthermore desired that this task sequence be adaptable for performance in a simulated EVA--specifically, that it be performed inside the Orbital Workshop as Experiment M508.

This section describes the work performed which resulted in a preliminary task sequence to meet these objectives. Basically, the study involved a detailed examination of various references and input data, summarization of the information in these references; filtering based on frequency and/or criticality, and, finally, development of a functional flow block diagram of a candidate experimental sequence.

3.1 STUDY INPUT DATA ANALYSIS

3.1.1 REFERENCE DOCUMENTS

An assortment of references dealing with simulation, specific experiments requiring EVA, and EVA in general was collected as input data to the Astronaut Performance Program. The input data was closely scanned to identify all human performance activities which, at least conceptually if not directly, could constitute manned extravehicular tasks. Particular attention was paid to the study of Extravehicular Engineering Activities by North American Rockwell Corporation. This study comprises an exhaustive look into the requirements for EVA capabilities needed to perform various experiments for the 1968-1980 time period.

3.1.2 EVA TASK DETERMINATION

In the North American EVEA study, 1212 experiments were identified and examined for potential EVA requirements. Approximately one-half of these required some degree of EVA support to satisfy the particular experiment objectives. Two-hundred and eighty experiments were examined in detail because they required EVA support and were planned for the time period of principal interest, 1971-1974. These 280 experiments included many redundancies and common functional requirements which were eliminated by further filtering, leaving 102 experiments for consideration. Finally, 16 experiments were selected as representative and investigated in detail for the specific EVA function required.

Eighty-four EVA functions were identified for the performance of these 16 experiments. Twenty-nine of these 84 functions were selected as being fully representative of the astronaut work performance requirements for the original 84. It was this detailed description of the 29 functions that served as a starting point for the present study.

The report states that-there are many optional ways of performing these tasks. All these options were tabulated under the title of "Building Blocks". Building Blocks permit a numerical categorization of EVA Functions, Sub-Functions, Techniques, Equipment and Gross Performance Measures. A logical combination of all these factors describe an EVA activity.

3.1.2 EVA TASK DETERMINATION (Continued)

Eighty-eight logical combinations of Building Blocks are identified in the report, 41 of which belong to the Work Performance function.

Of the 88 combinations, 22 are found to account for 90% of all EVA identified in the 16 experiments studied. Ten of these 22 belong to the Work Performance Function, and the Work Performance Experiment is based on these 10.

3.2 TASK ANALYSIS

In order to keep track of the information generated, an Experiment Description Form was prepared. The first important heading in the Experiment Description sheet is the "EVA Task Description" (Figure 3-1). Under this heading, the particular function being performed by the astronaut is detailed in a step-by-step procedure. Since the primary interest was in performance at a stationary worksite, translation and egress/ingress functions were not broken down into fundamental movements. All astronaut actions, however, which do take place at a worksite are listed in a sequential order.

The remainder of the form details support equipment and interface equipment which is used in performing the EVA task. Restraint requirements are defined in terms of functional capabilities which are required. Also noted are work envelope, visual acuity, access requirements, tool requirements, and expected man-equipment interfaces.

After completing 28 such forms, there existed a comprehensive data bank from which to select the experimental sequence, but in order to be more useful, the data was summarized. In this way, "typical tasks" were determined based on frequency counts, criticality or importance.

Table 3-1 presents a listing of all tasks which were included in the step-by-step breakdown of EVA functions from the North American Rockwell report. The wording of these tasks is precisely as was used in formulating the detailed procedures. No attempt was made here to combine tasks on the basis of commonality, since it was felt that such combination might result in lost information.

Comparisons were made across experiments to discover the frequency of occurrence of each task item. The first column of Table 3-1 lists the total number of times an item was encountered. The second column lists the total number of experiments in which an item was encountered. It is a combination of these two columns which constitutes a "high frequency" occurrence of an item, since considering total occurrences above might yield an item with "many" occurrences but which was germane to only one experiment and therefore not "typical" of EVA requirements.

The remaining columns of Table 3-1 list those items which are determined to be desirable or undesirable for evaluation, and the reasons for such decisions. Three justifications are considered to determine the desirability of a task. First, a task may be desirable on the basis of a high frequency of occurrence. In order

TABLE 3-1 TASK SUMMARIZATION

			DESIRABILITY					
			DESIRABLE			NOT DESIRABLE		
	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	BASED ON FREQUENCY	BASED ON IMPORTANCE	BASED ON COMMONALITY	NOT AFFECTED BY 0-G, ETC.	NOT SUITABLE FOR CABIN SIMULATION	NOT WORKSITE PERFORMANCE
Install Restraints	63	28	X					
Detach & Stow Restraints	63	28	X					
Restrain Self	91	28	X					
Reposition Self	23	10	X					
Release Self	91	28	X					
Secure Cargo Harness	48	16	X					
Release Cargo Harness	48	16	X					
Open Hatch	37	20	X					
Close Hatch	36	19	X					
Attach Equip. Tether	88	19	X					
Release Equip. Tether	88	19	X					
Release Cassette Latch	1	1			X			
Unscrew Three Captive Screws	1	1			X			
Release Three Instrument Lugs	1	1			X			
Release Pip Pins	3	3			X			
Remove (Stowed) Foot Restraints	1	1			X			
Remove (Stowed) Solar Panel Rack	1	1			X			
Remove (Stowed) Handheld Sensors	1	1			X			
Remove (Stowed) Cargo Transp.	3	3			X			
Remove (Stowed) Cargo Module Guide Tether	1	1			X			
Remove (Stowed) ACS Units	2	1			X			
Remove (Stowed) AMU	4	4			X			
Remove (Stowed) Umbilical Lines	3	2			X			
Remove Module	16	7	X					
Remove Camera	2	2			X			
Remove Cassette	9	4		X				
Remove Solar Panel	6	1		X				
Remove Fastener	1	1		X				
Remove Launch Supports	1	1		X				
Position Focus Plate	1	1		X				
Remove Focus Plate	1	1		X				
Remove Module from Container	1	1				X		

TABLE 3-1 TASK SUMMARIZATION (Continued)

	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	DESIRABILITY: DESIRABLE — BASED ON FREQUENCY	DESIRABILITY: DESIRABLE — BASED ON IMPORTANCE	DESIRABILITY: DESIRABLE — BASED ON COMMONALITY	DESIRABILITY: NOT DESIRABLE — NOT AFFECTED BY 0-G, ETC.	DESIRABILITY: NOT DESIRABLE — NOT SUITABLE FOR CABIN SIMULATION	DESIRABILITY: NOT DESIRABLE — NOT WORKSITE PERFORMANCE
Activate Electrical System	2	1		X				
Activate Life Support System	2	1		X				
Energize Switch	3	1				X		
Checkout Electrical System	2	1		X				
Checkout Life Support System	2	1		X				
Rotate Shaft	2	2		X				
Rotate Turret	1	1		X				
Observe (Fine)	1	1		X				
Observe (Gross)	11	5	X					
Attach Hose to Connector	10	2	X					
Detach Hose from Connector	10	2	X					
Make Sensor Measures	27	1	X					
Adjust Antenna Mesh	1	1				X		
Discard Module	1	1					X	
Extend Boom (Crank)	1	1			X			
Pull Lanyard	15	2	X			X		
Secure Lanyards	4	1				X		
Don AMU	4	4						X
Doff AMU	4	4						X
Stow Equipment	1	1			X			
Stow Lanyard & Shroud	6	2				X		
Stow Transporter	1	1			X			
Stow AMU	4	4			X			
Stow Hose	3	2			X			
Stow Package	1	1			X			
Inspect	6	1		X				

TABLE 3-1 TASK SUMMARIZATION (Continued)

			DESIRABILITY					
			DESIRABLE			NOT DESIRABLE		
	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	BASED ON FREQUENCY	BASED ON IMPORTANCE	BASED ON COMMONALITY	NOT AFFECTED BY O-G, ETC.	NOT SUITABLE FOR CABIN SIMULATION	NOT WORKSITE PERFORMANCE
Install Module in Container	1	1				X		
Attach Cassette to Cargo Harness	9	4		X				
Attach Foot Restraints to Cargo Harness	1	1		X				
Attach Solar Panel Rack to Cargo Harness	1	1		X				
Attach Module to Cargo Harness	12	5	X					
Attach Handheld Sensors to Cargo Harness	1	1		X				
Release Cassette from Cargo Harness	6	3		X				
Release Module from Cargo Harness	12	5	X					
Release Foot Restraints from Cargo Harness	1	1		X				
Release Handheld Sensors from Cargo Harness	1	1		X				
Restrain Cassette	6	3		X				
Restrain Module	8	5		X				
Restrain Camera	2	2			X			
Restrain Fan	2	1			X			
Restrain Solar Panel	6	1		X				
Restrain Fastener	1	1		X				
Restrain Launch Supports	1	1		X				
Release Solar Panel from Restraint	6	1		X				
Release Module from Restraint	8	5		X				
Release Launch Supports from Restraint	1	1		X				
Release Cassette from Restraint	6	3		X				
Release Camera from Restraint	2	2			X			
Release Fan from Restraint	2	1			X			
Release Fastener from Restraint	1	1		X				
Obtain Boom from Cargo Harness	1	1			X			

TABLE 3-1 TASK SUMMARIZATION (Continued)

	TOTAL OCCURRENCES	NUMBER OF EXP'S. WHERE ENCOUNTERED (Max. Poss. 28)	DESIRABILITY: DESIRABLE — BASED ON FREQUENCY	BASED ON IMPORTANCE	BASED ON COMMONALITY	DESIRABILITY: NOT DESIRABLE — NOT AFFECTED BY 0-G, ETC.	NOT SUITABLE FOR CABIN SIMULATION	NOT WORKSITE PERFORMANCE
Obtain Exp. Pkg. from Cargo Harness	5	2			X			
Obtain Tube of Filler Compound	1	1				X		
Obtain Plug & Tool	1	1				X		
Obtain Drill	1	1				X		
Attach Transporter End	7	4					X	
Detach Transporter End	3	2					X	
Attach Module to Transporter	6	4					X	
Release Solar Panel from Rack	14	2	X					
Release Transporter Roll-up Ties	1	1				X		
Operate Gas Bottle Valve	2	1			X			
Adjust Transporter Tension	3	3				X		
Operate Transporter	6	4					X	
Insert Power Tool	2	2		X				
Drill Hole	1	1					X	
Operate Power Tool	1	1		X				
Remove Power Tool	1	1		X				
Secure Drill	1	1				X		
Secure Tube	1	1				X		
Insert Plug & Tool	1	1				X		
Fill Hole	1	1					X	
Install Panel	14	2	X					
Install Cassette	6	3		X				
Latch Cassette	1	1		X				
Install Module	14	6	X					
Install Camera	2	2			X			
Install Boom	1	1			X			
Install Exp. Pkg.	6	3			X			
Install Fan	1	1			X			
Install Fastener	1	1		X				
Make Electrical Connection	12	4	X					
Break Electrical Connection	12	4	X					
Activate Motor	4	1				X		

MASS HANDLING:

SIZE	SHAPE
MEDIUM	CANISTER-SHA

RESTRAINT REQUIREMENTS:

MOBILITY

EXPERIMENT DESCRIPTION

SOURCE: EXTRAVEHICULAR ENGINEERING ACTIVITIES (EVEA) PROGRAM
NORTH AMERICAN ROCKWELL CORPORATION, MAY, 1968.

EXPERIMENT NUMBER:	AE0502RE
EXPERIMENT TITLE:	ONE METER TELESCOPE, EXPERIMENT PACKAGE
FUNCTION:	REMOVE AND REPLACE FILM
FUNCTION DESCRIPTION:	DATA CAPABILITY OF BY EVA REPLACEMENT OF RETRIEVES FIRST CASSETTE NEW ONE IN PLACE.
EQUIPMENT DESCRIPTION:	25 LB. FILM CASSETTE,
EVA TASK DESCRIPTION:	ASTRONAUT EGRESSES TRANSLATES (20 FT.) TO CASSETTE ATTACHED TO

1. INSTALLS RESTRAINTS
2. RESTRAINS SELF
3. SECURES HARNESS AT
4. OPENS OUTER HATCH
5. OPENS INNER HATCH

FOLDOUT FRAME 1

TYPES	DEF.	POSS.	QUANT.	QUAL.	QUANT.	QUAL.	CHARACTERISTICS	DESCRIPTION OF EQUIPMENT FUNCTION
FASTENERS								
LEVER (LATCH)	X	—	—	SMALL	—	LOW		LATCHES SECURE CASSETTE IN POSITION
TURN	—	—	—	—	—	—		
SLIDE	—	X	—	SMALL	—	LOW		FOR LANYARD ATTACHMENT/OR OR RESTRAINT ATTACHMENT

TOOL REQUIREMENTS

TYPE	USAGE IN EXP. DEF.	POS.	UNIT SIZE QUANT.	QUAL.	CHARACTERISTICS	FORCE REQ'D. QUANT.	QUAL.	DESCRIPTION OF TOOL FUNCTION
SCREWDRIVER	—	—	—	—		—	—	
DRILL	—	—	—	—		—	—	
T-HANDLE WRENCH	—	X	—	MEDIUM		—	MEDIUM	USE TO OPEN HATCH
FINGER WRENCH	—	—	—	—		—	—	
CRANK HANDLE	—	X	—	MEDIUM		—	MEDIUM	USE TO OPEN HATCH
CRIMPER-STRIPPER	—	—	—	—		—	—	
LANYARD	—	—	—	—		—	—	
CARGO HARNESS	X	—	100 LB. MAX.	LARGE		—	HIGH	TRANSPORT CASSETTES
						—	—	
						—	—	NOTE: ASSUMPTION THAT CASSETTE IS RESTRAINED TO CARGO HARNESS BY TETHER.
						—	—	

ACCESS REQUIREMENTS/CONDITIONS

TWO HAND ACCESS

REACH WITH BOTH HANDS 6 TO 20 INCHES ☐
REACH WITH BOTH HANDS FULL ARMS LENGTH (+20) ☒

ONE HAND ACCESS

EMPTY HAND TO WRIST ☐
CLENCHED HAND TO WRIST ☐
HAND + 1-INCH DIAMETER OBJECT TO WRIST ☐
HAND + OBJECT 1 INCH ☐
ARM TO ELBOW ☐
ARM TO SHOULDER ☐

FINGER ACCESS

MAN PERFORMANCE REQUIREMENTS

WORK ENVELOPE REQUIREMENTS:

WORK SPACE DEPTH — ONE HAND — TWO HANDS	CLOSE	OPTIMUM	EXTENDED X
WORK SPACE HEIGHT — ONE HAND — TWO HANDS	HIGH	OPTIMUM X	LOW
WORK SPACE WIDTH — ONE HAND PREF. — TWO HANDS PREF. — ONE-HAND NON-PREF. — TWO-HANDS NON-PREF.	CLOSE	OPTIMUM X	EXTENDED
VISUAL ACUITY REQUIREMENTS	HIGH	MEDIUM X	LOW
			LOW X

EQUIPMENT REQUIREMENTS

WEIGHT	DISTANCE	MANIPULATION	HANDLING MODE
25 LB.	2-3 FT.	GROSS POSSIBLY FINE ON REPLACEMENT	NONE GRASPS CASSETTE

NO AMOUNT — REPOSITIONING DURING TASK REQUIRED

IS STUDY,

ION

ANCED
ONAUT

NEW

FIGURE 3-1 EXPERIMENT DESCRIPTION FORM

3.2 TASK ANALYSIS (Continued)

to qualify a task as desirable on this basis, an individual item had to satisfy at lease one of the following arbitrary criteria: (a) exhibit a total frequency of occurrence of 10 or more (the mean number of occurrences per item in Table 3-1 is 9.3), or (b) occur in at least 7, or 25%, of the experiments detailed.

Second, a task may be desirable based on its importance and/or uniqueness. A task item was considered "important" because of its criticality to successful completion of an experimental EVA function, or because of its anticipated existence in future EVA.

Finally, a third column is included to note those task items, which, while not necessitating evaluation per se, are nevertheless desirable and are evaluated by virtue of commonality with other, more desirable tasks.

Task items are classified as "Not Desirable" for evaluation etiher because the Task (1) is not seriously affected by 0-g, restraints, or suits, or (2) cannot be suitably evaluated inside the Orbital Workshop, or (3) does not constitute "performance at a worksite".

3.2.1 CANDIDATE VARIABLE ANALYSIS

In addition to the Task Summarization efforts described above, the remainder of the information contained in the Experiment Description Sheets was analyzed and evaluated to derive potential experimental variables. These data were evaluated for the purpose of identifying potential independent and dependent variables for manipulation and measure in the experiment program. No attempt was made at this time to develop specific variables or measures; rather, the aim was to specify the types and ranges of the potential experimental condition combinations and measures.

3.3 FACTORS AFFECTING EVA PERFORMANCE

Since the purpose of this program was the qualitative and quantitative assessment of astronaut performance as a function of weightlessness, pressurized space suits, various restraint methods, etc., the effects of those characteristics must be identified and delineated to determine their effects on task sequences, experimental and test hardware design. Also, potential interaction effects between the primary variables which might influence astronaut performance were to be specified.

It was recognized that all of the parameters which were discussed could not be incorporated into the program. However, consideration had to be given to each of the identified effectors of performance in order to provide an adequate documented rationale to support the inclusion or exclusion of the various potential performance effectors in question.

Selection of the experiment test parameters was further constrained by the limits imposed by the vehicle, power, volume, mass and flight programming allocations available as well as the physiological and psychological capabilities of the flight crew. It was essential that all potential constraints be diligently identified and

3.3 FACTORS AFFECTING EVA PERFORMANCE (Continued)

quantified and that appropriate trade-offs be performed and documented to provide justification for the "final" selected test program. Further, constraints imposed on the experimental design by the required psycho-physiological and psycho-motor condition of the flight crew had to be defined and documented.

3.4 DEFINITION AND SELECTION OF INDEPENDENT VARIABLES

The major independent variables for this experiment were originally defined in the M508 Experiment Implementation Plan provided for guidance as part of the study input data. The information provided in that document are listed below:

1. Type of Restraint
   a. Capsular Adhesive Handhold
   b. Variable Flexibility Waist Tether
   c. Gemini Dutch Shoes
2. Suits
   a. Apollo Block II
   b. Litton Hard Suit

The manipulation and combination of these items into an experimental design was one purpose of the program. As a result of the analysis performed on the study input data, the following decisions were made concerning the definition of the experimental design. The Waist Tether and Dutch Shoes were to be used separately and in combination and evaluated across all other experimental conditions. The Handhold would be used only for installing the other restraints. The suits were to be used separately and evaluated across all other experimental conditions.

At this point it was considered necessary to re-examine the basic ground rules of the Experiment Implementation Plan concerning the selection of suit and restraint conditions to be evaluated. Two separate analyses were undertaken to perform the re-evaluation. The first of these was to consider the experimental design for its applicability to IVA Tasks, and the second was to consider other types of restraints.

The results of the first analysis indicated that the experimental design is applicable to both EVA and IVA operations and added the shirtsleeve mode to the list of suit conditions.

The results of the second analysis indicated that while no single restraint could satisfy all the requirements for an optimum restraint, the three chosen seem to be among the best, and the limitation on available time to perform the experiment would not allow sufficient evaluation of additional restraints should they be added.

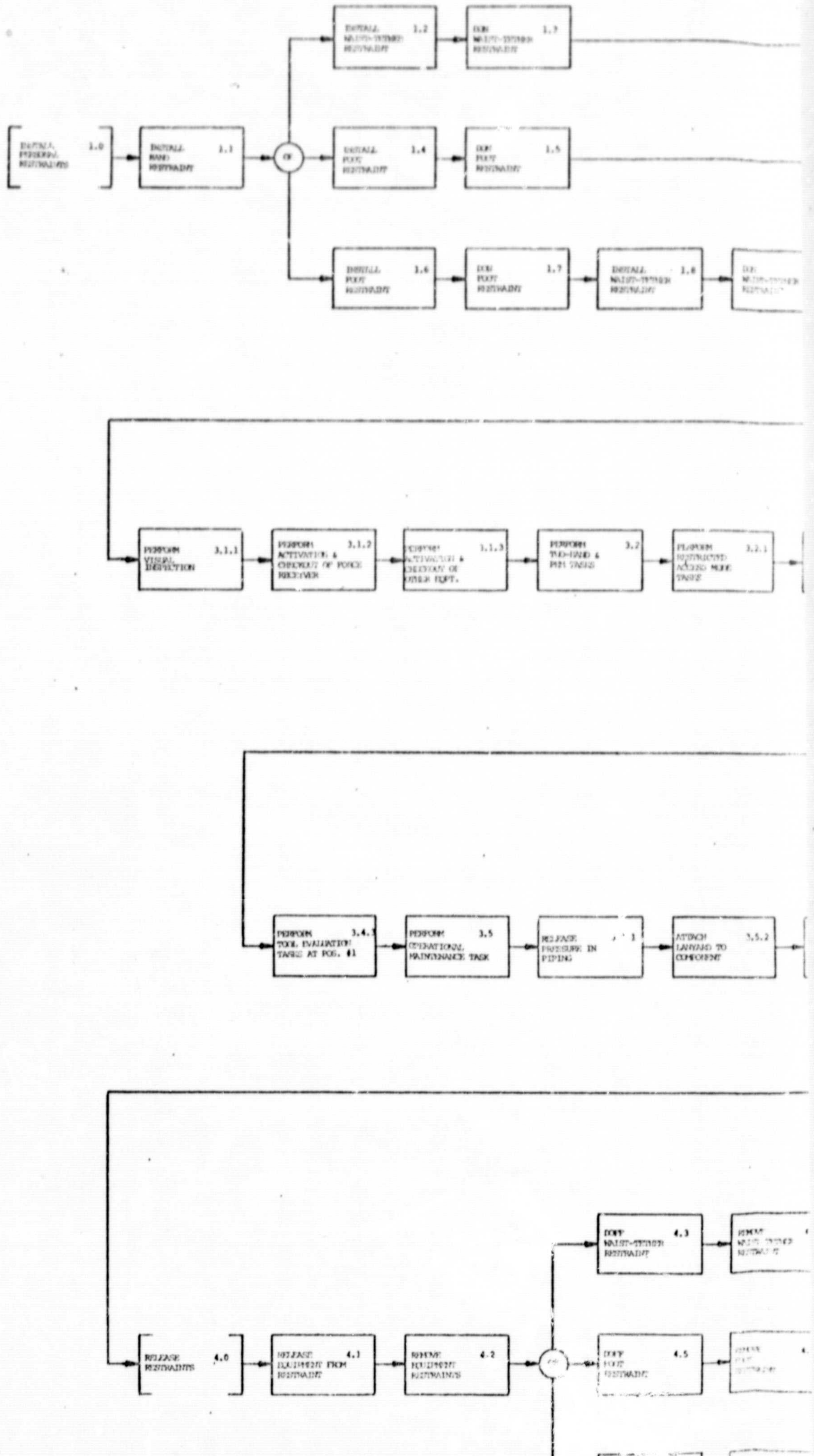
3.5 CANDIDATE TASK SEQUENCE

The analysis described above resulted in the generation of a sequence of tasks which comprised the definition of the M508 Experiment. The tasks were set into an ordered sequence to approximate an actual manned intra-or extra-vehicular function. The sequence as it ultimately evolved is shown as a Functional Flow Block Diagram in Figure 3-2.

Each performance of the task sequence requires approximately 1 hour of subject time and is to be performed under the following conditions:

Subjects	- 2	
Suit Conditions	- 3	- Shirtsleeves Apollo Block II AES
Restraint Conditions	- 3	- Variable Flexibility Waist Tether Gemini Dutch Shoe Waist Tether and Dutch Shoe
Replications	- 2	

These combine for a total of 36 experiment sessions, which can be performed in zero-g conditions (real or simulated). In a 1-g environment, the "Waist Restraint Only" condition must be deleted, leaving only 24 sessions.



FOLDOUT FRAME

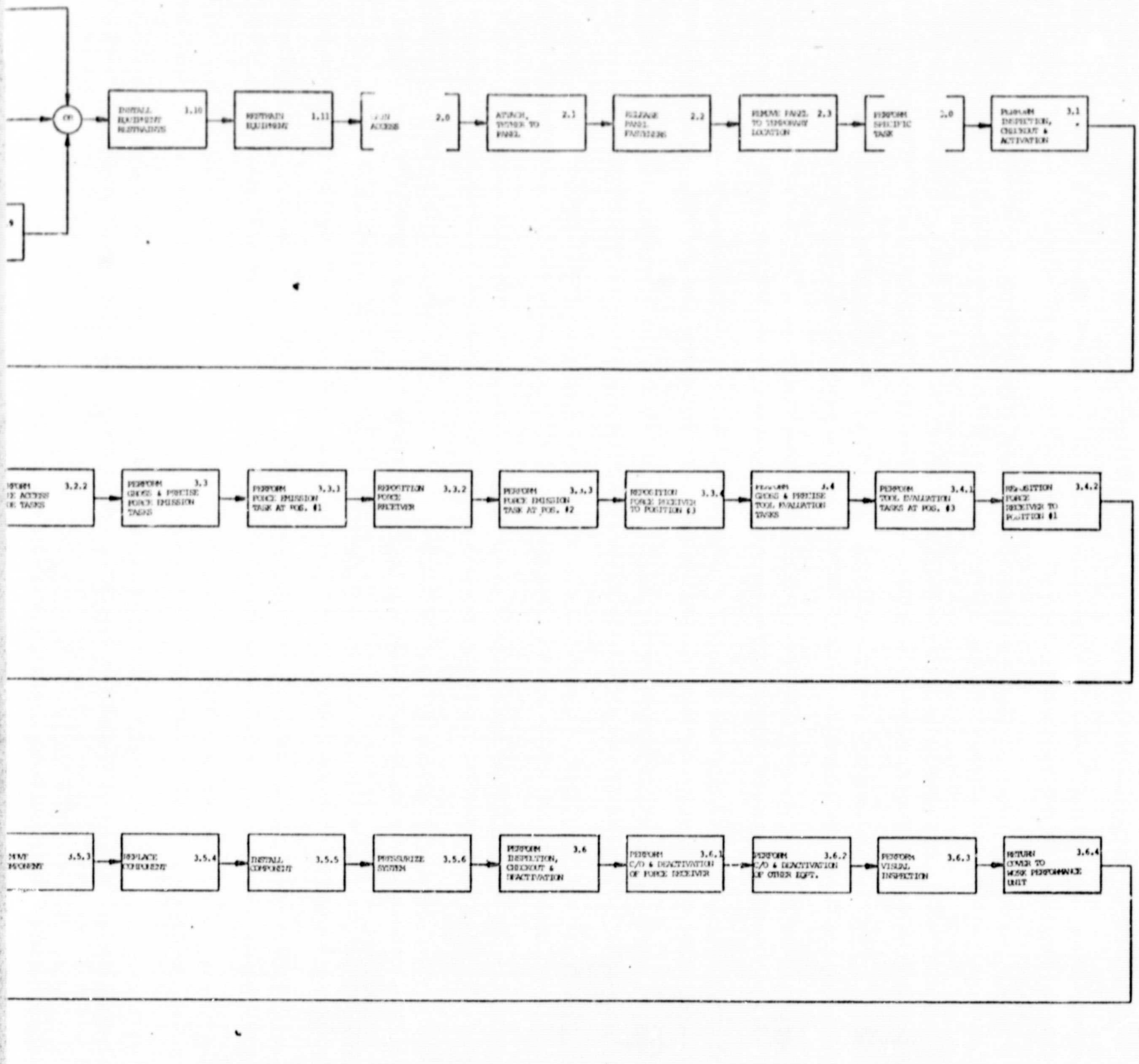


FIGURE 3-6: M508 EXPERIMENT SEQUENCE FUNCTIONAL FLOW BLOCK DIAGRAM

FIGURE 3-2 M508 EXPERIMENT SEQUENCE FUNCTIONAL FLOW BLOCK DIAGRAM

SECTION 4

TASK PANEL DEVELOPMENT

4.1 TASK PANEL EVOLUTION

The development of the task panel followed an iterative process that closely paralleled the development of the task sequence. An initial candidate task sequence was defined through the analytical steps described in Section 3.0. This sequence was then used as the basis for determining the task panel functional and design requirements. Simultaneous with and integrated into the development of the functional and design requirements was the specification of the man/machine interface criteria to be utilized in the development of the task panel system. The above steps resulted in a task panel conceptual design that specified as many design details as possible and identified design questions that required further investigation. A feasibility test program was accomplished to answer the unresolved design questions and the results were used to finalize the task panel design. The following sections detail the efforts accomplished in the evolution of the task panel hardware design.

4.1.1 FUNCTIONAL AND DESIGN REQUIREMENTS

A Functional and Design Requirements Specification was prepared to provide the interface information between the Candidate Task Sequence data and the equipment design details. It converted experiment requirements into information required for hardware design, and it also served as an initial reference point for identifying equipment required to perform the experiment both in the various ground-based simulation media and in the space situation.

4.1.2 MAN/MACHINE INTERFACE CRITERIA

Fundamental to the Task Panel design requirements were the Man/Machine interface Criteria which were selected both for investigation in the experimental program and for general applicability to the Task Panel design. A document containing this information was prepared from information derived from several pertinent human engineering documents. It is important to note that in a human factors experiment such as this, the requirements of the specifications must be understood completely and applied judiciously--especially in those situations where a definitive requirement in a specification is a variable for manipulation in the experiment.

4.1.3 CONCEPTUAL DESIGN

The design of the hardware, while starting with no physical constraints, was approached with the intent of being readily adapted to the AAP Orbital Workshop (OWS) as the equipment for Experiment M508. With this in mind, serious efforts were made to determine the requirements imposed on the experiment by the vehicle and factor these into the design within the practicalities of schedule and cost. Several sources of information were used to determine the OWS/Experiment interface requirements. Among those were documents such as the M508

4.1.3 CONCEPTUAL DESIGN (Continued)

Experiment Implementation Plan (EIP), Experiment Integration Requirements Document (EIRD), and the AAP Experiment General Requirements Document. It was determined from these documents that the stowed volumes allocated for the Task Panel and Restraints Container were 30 x 24 x 24 inches and 12 x 12 x 12 inches, respectively, and it was considered essential to stay within, or if possible, reduce these dimensions. The design of the restraints and task panel was two separate but related and integrated problems, and the efforts to achieve a cohesive experiment hardware concept with these two items is discussed individually below.

4.1.3.1 Restraints

Although the restraints were to be GFE, they had to be integrated into the experiment operations to insure successful completion of the experiment. The restraints defined in the EIP were:

1. Handhold
2. Variable Flexibility Waist Tether
3. Gemini Dutch Shoes

The EIP also indicated the use of an adhesive device for the Handhold Restraint in the flight experiment, but in this program, mechanical attachment was utilized.

The Waist Tether was to consist of two electrically actuated Variable Flexibility units mounted to a single belt. The device supplied for this program was a prototype model with mechanical actuation and Vise Grips mounted to the distal end for attachment at the worksite.

The Gemini Dutch Shoes were to be supplied as an unaltered pair, but in view of the requirement for the subject to bring his restraints to the worksite and install them with one hand, it was decided to mount the shoes on a platform containing a handle and locking device. Figure 4-1 is a picture of the Shoe Restraint and illustrates the handle placement.

Utilizing these restraint concepts, it was determined that the Restraint Container would have to be larger than originally described in the EIP. A container 18 x 18 x 12 inches was determined to be the smallest size capable of holding the restraints. In addition, it was noted that the Restraint Container could serve another purpose as the mounting point for the Shoe Restraint in the flight experiment.

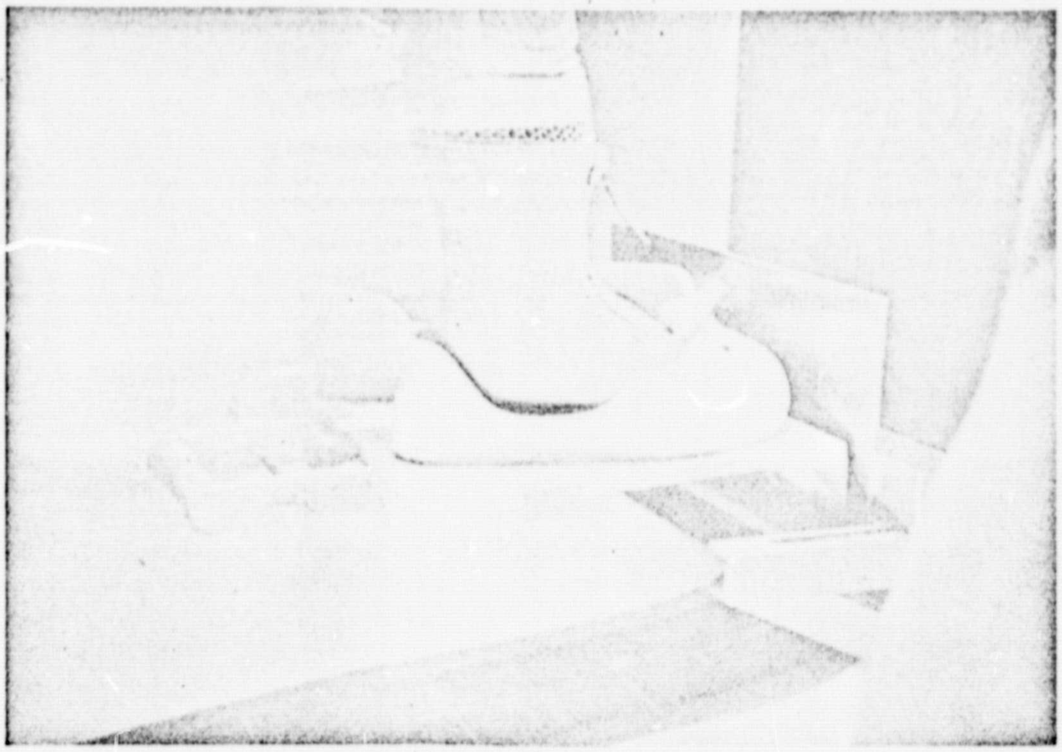


FIGURE 4-1 SHOE RESTRAINT

4.1.3.2 Task Panel

Figure 4-2 illustrates the initial Task Panel concept in the deployed state. The major, working elements were located in one-half of the box mounted to the wall as shown. The other half of the box was split in two sections and mounted to the wall to form receptacles for the module handling task. The remainder of the receptacle boxes would be used to store tools, cargo harness, tethers, and other small items. One of the most serious problems encountered in this design was the placement of the various components in the most appropriate location with respect to the test subject's one- and two-hand reach and visual access. For example, the center of the force receiver handle was to be positioned directly in front of the subject's right nipple, and the displays containing the command and cue indicators were to be located at eye level with unobstructed visual access.

At this point, the decision was reached that the modular concept for the individual tasks was the most desirable since it afforded the highest level of flexibility for the overall experimental design.

The locations selected for the various elements of the Task Panel and its overall layout were based on a series of 1-g static tests using in-house personnel with several mock-up configurations.

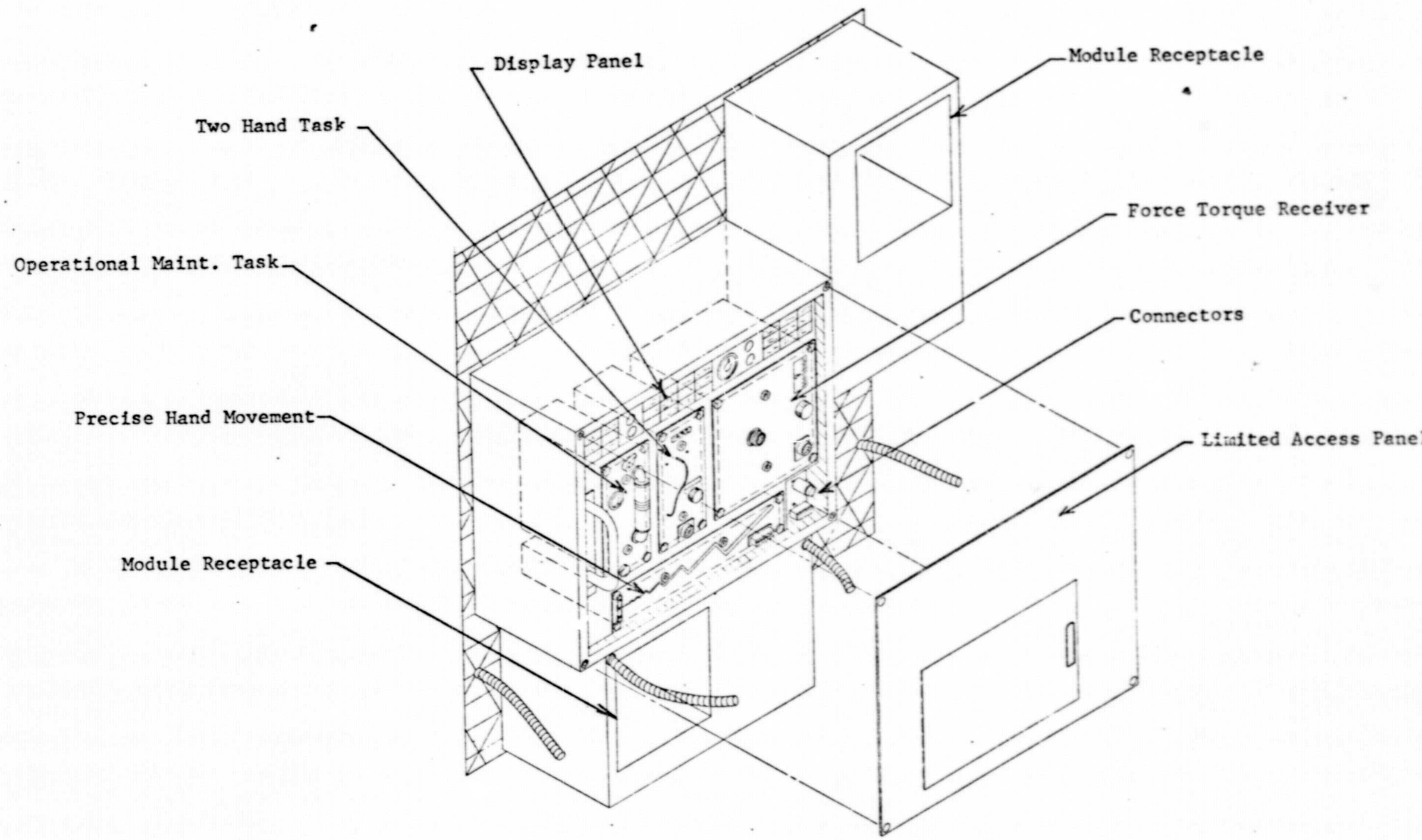


FIGURE 4-2. TASK PANEL CONCEPT

4.1.4 FEASIBILITY TESTING

A series of simulated zero-g tests were conceived and conducted to insure that all the tasks described in the Candidate Task Sequence and then developed into a hardware concept could be performed by a test subject in a pressurized suit within the prescribed limitation of time and work envelope. It was originally planned to perform the feasibility tests once, but sufficient problems were encountered to warrant performing a second test after the data had been analyzed and the necessary changes incorporated. Portions of the tests were performed on two different occasions and were identified as Feasibility Tests Phase I and Phase II.

The tasks selected for feasibility testing were performed in gross fashion only, to determine simply the GO or NO/GO status of the task and some nominal design requirements. The equipment consisted of mass and shape mock-ups necessary to properly simulate the man/machine interface and data recording was in the form of motion pictures, task-times, and subjective comments.

All tests were performed using neutral buoyancy simulation of zero-gravity, with the test subjects (95th percentile) wearing an Apollo A5L spacesuit pressurized to 3.5 $\pm$ .2 psi over ambient. Two-way communication between the subject and topside test director was provided.

4.2 TASK PANEL DESIGN

The results of the Feasibility Tests described above provided information for major changes to the original concept. Figure 4-3 depicts the final Task Panel configuration in the deployed configuration. The first of the changes was a reduction in size of the Force Receiver Module from 12" x 12" x 12" to 10" x 10" x 9.5" deep and a change in location of the two extreme receptacle positions. The lower-left receptacle was elevated to a position within the main frame, while the upper-right receptacle was moved toward the center from its originally conceived position. These changes allowed a reduction in the overall depth of the Task Panel from 24 to 20 inches. The two other major changes were the relocation of the Precise Hand Movement Task Module to the upper level and the Force/Torque Task Cue Panel to a position on top of the main frame. These changes also meant that there would be an increase in the time required to deploy and set-up the Task Panel for operation.

The four main task modules, the Force/Torque Receiver, Precise Hand Movement, Operational Maintenance and Two Hand Task are located in the upper part of the Task Panel. This is a direct result of the Feasibility Tests and was done to optimize the location of each task. The lower portion contains the Cue Panel, upper-right position receptacle and the observers panels. The position occupied by the Cue Panel becomes the lower-left receptacle for the Force/Torque Receiver.

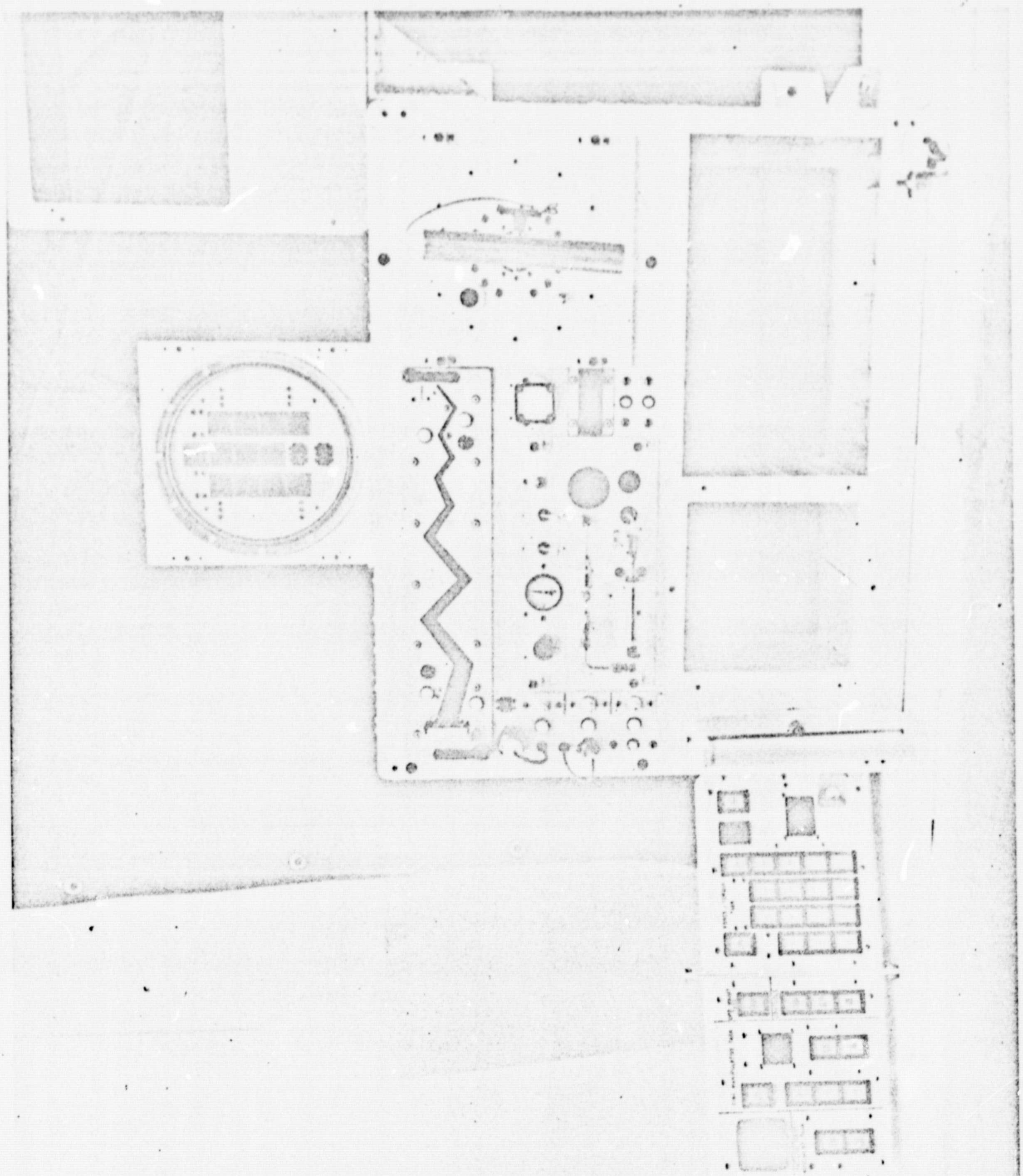


FIGURE 4-3 TASK PANEL-FINAL CONFIGURATION

4.2 TASK PANEL DESIGN (Continued)

It should be specifically noted that the design of the Task Panel described here was mainly for use in the four simulation modes; neutral buoyancy, KC-135 Keplerian flights, 6 degree-of-freedom mechanical, and 1-g. The requirements of the first two of these established the environmental design parameters for models built in this program. That is, the neutral buoyancy mode required that all electrical and electronic parts and/or connections be sealed or otherwise operable underwater, and the KC-135 required structural integrity that would survive the impact of a crash landing. The results of these requirements can be partly observed in Figure 4-3. For instance, the Cue Panel is a sealed pressurized can, as is the Force/Torque Receiver Module.

The design also incorporates the concept of using parts of the Task Panel for more than one purpose. For instance, the Force Receiver serves as the equipment for the Module Removal/Replacement Task.

The Main Frame is a welded, riveted structure which provides the main load carrying members of the entire Task Panel including the mounting. Removable covers are provided on the back, sides, top and bottom, with side covers containing recessed carrying handles. The front face is a sheet metal skin which is riveted to the main structure.

4.2.1 RESTRAINTS

As stated previously, the restraints used in this program were a Handhold, Variable Flexibility Waist Tether, and Gemini Dutch Shoes. All three were designed and/or modified so that the attachment to the worksite was by means of double-acting ball-lock pins.

4.2.1.1 Handhold Restraint

Figure 4-4 shows the Hand Restraint, mounted in the Task Panel cover. This is the first restraint to be installed in the Task Sequence and is used to assist in donning the other restraints. The long thin rod is used to unlock the pin.

4.2.1.2 Variable Flexibility Waist Tether

The variable flexibility tether can be varied from a state of ropelike flexibility to a degree of rigidity that effectively restrains a pressure suited astronaut while he is performing any work tasks within his current task spectrum. Additionally, the tether may be rigidized to an intermediate "plastic" state to permit minute changes in its configuration. This permits the astronaut to make precise adjustments in his position relative to his task site while he is adequately restrained by the partially rigidized tether.

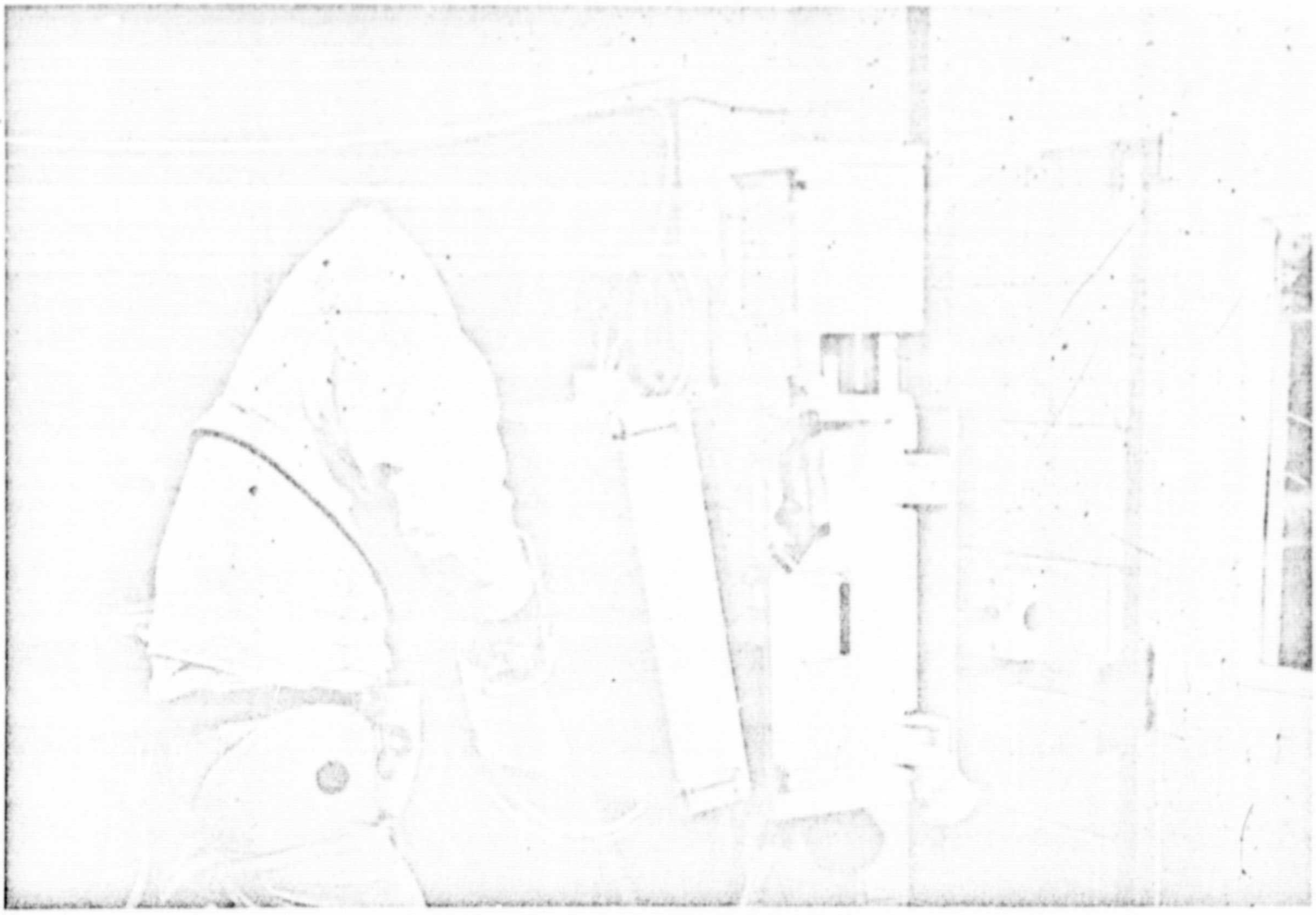


FIGURE 4-4 HAND RESTRAINT INSTALLED IN COVER

4.2.1.2 Variable Flexibility Waist Tether (Continued)

The Variable Flexibility Waist Tether used in this program is shown in Figure 4-5. The mechanism with the handle at the subject's side is the take-up and release mechanism. Also shown in this picture are the retractable lanyards on the subject's waist and wrist used to retain the shoe restraint during transport and the tools required for the experiment operations, respectively.

4.2.1.2 Foot Restraint

Figure 4-6 illustrates the foot restraint. The Handle over the toes is for installation and release. The shoes used were developed to accomodate the Gemini suit boot and, consequently, fit the A7L suit. However, the boots of the AES suit did not interface properly, and therefore, it was necessary to remove the back section of the shoes whenever that suit was utilized.

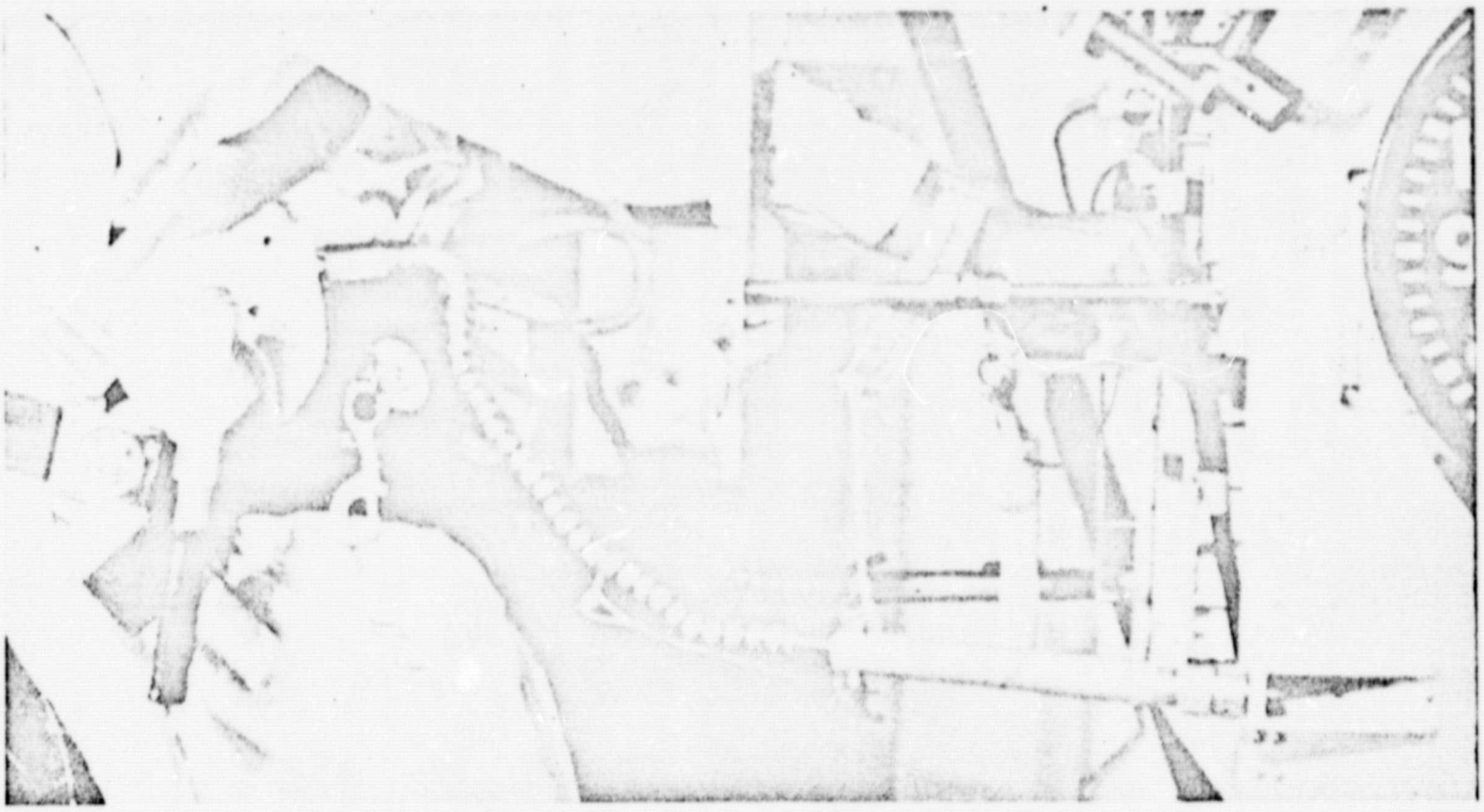


FIGURE 4-5 VARIABLE FLEXIBILITY WAIST TETHER

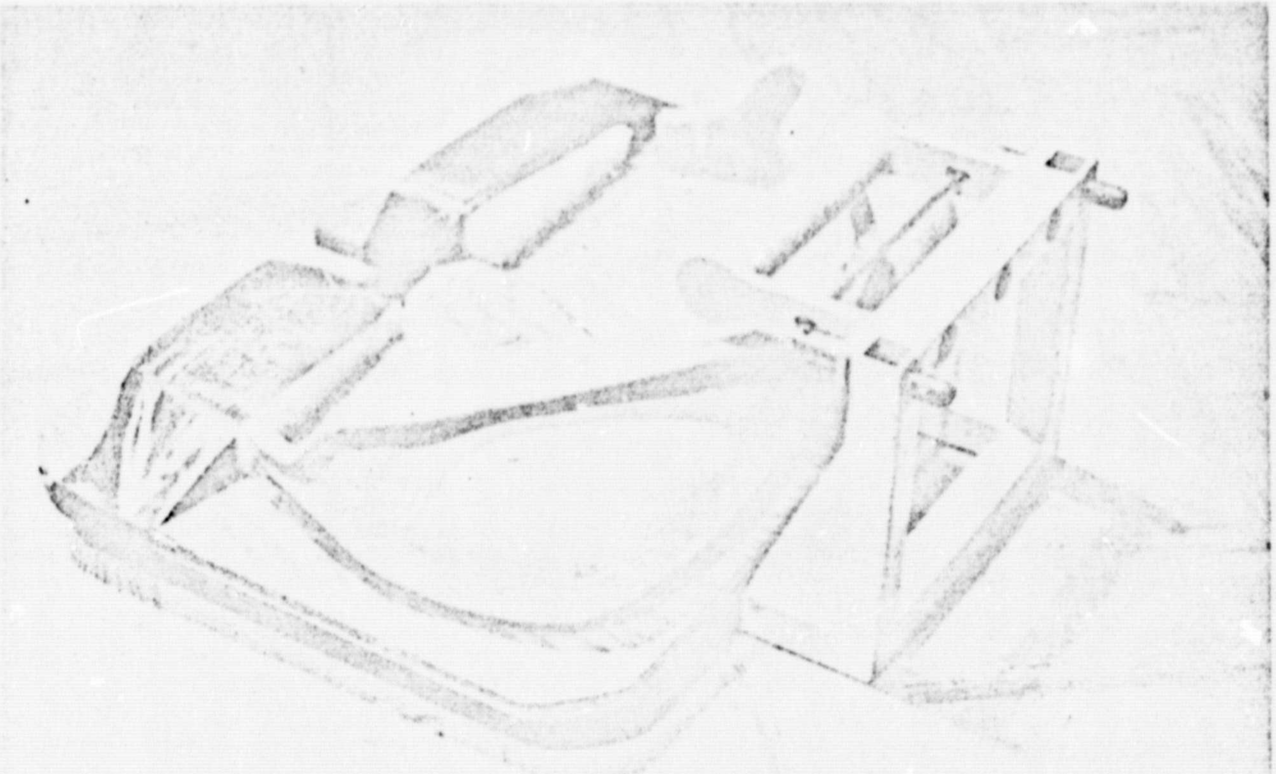


FIGURE 4-6 FOOT RESTRAINT

4.2.2 ELECTRONICS PACKAGE

An exception was made to the Task Panel volume limitations with the electronics packaged separately, Figure 4-7. However, sufficient volume was retained inside the Task Panel to allow the electronics to be packaged therein to satisfy the volumetric requirements as stated above.

The electronics package, contains all of the power supplies, command logic, control and signal processing circuits associated with the Task Panel. The input power to the Task Panel was specified in the AAP Experiment General Requirements Specification as 28 VDC unregulated, ranging from 24 to 32 volts. This input voltage is reduced to -15V, +5V, +3V with solid state power supplies for use in the system, thus keeping well under the lowest point of the input supply tolerance, and independent of primary power variations. The only components using the raw input power were selected to operate over a wide range of voltage so an additional power supply is not required. Each task module has its own circuitry i.e. power supplies, command logic, and output signal processing. Thus, a failure in one will not preclude operation, and thus, data collection from the others.

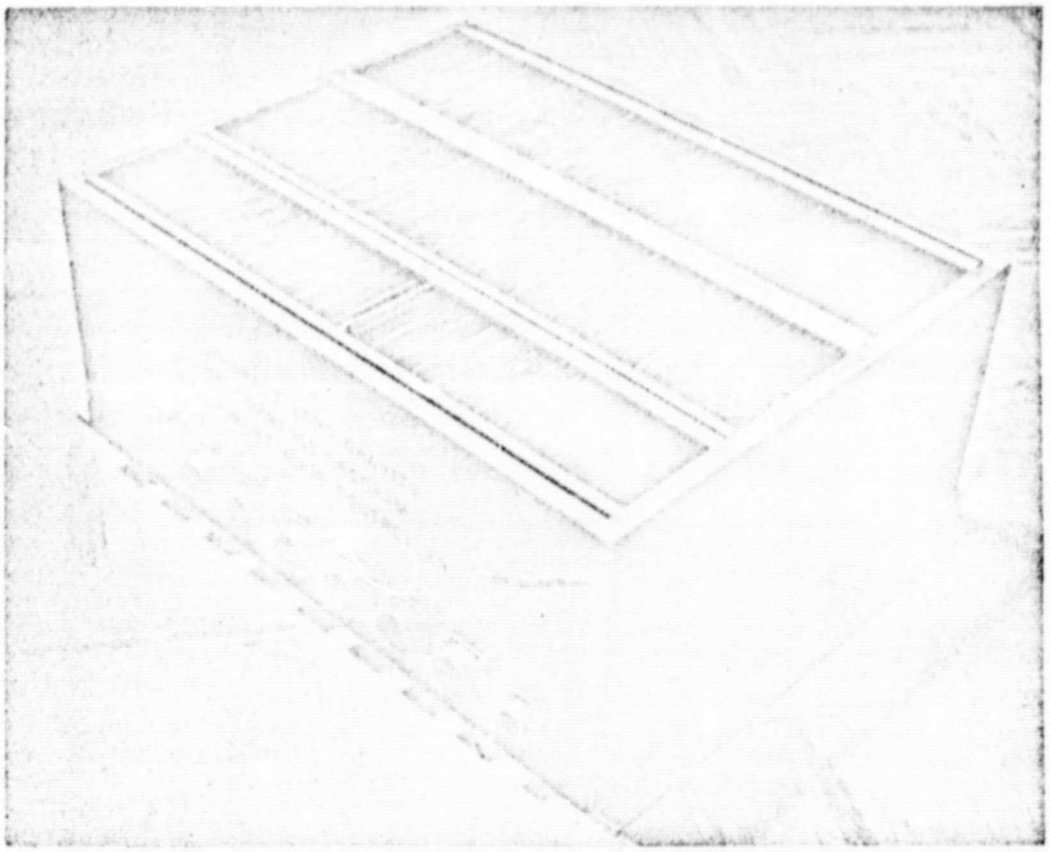


FIGURE 4-7 ELECTRONICS PACKAGE

4.2.3 AAP VEHICLE AND OTHER EXPERIMENTS INTEGRATION

Early in the Task Panel development phase of the program, efforts were undertaken to identify and define the requirements for integrating the Task Panel into the AAP OWS. There were two areas of consideration; stowage for launch in the MDA, and deployment for operation in the experiments area of the Workshop. Since there was no planned use of the Task Panel in the MDA, the interfaces to be considered there were weight, volume, mounting, and environmentally induced loads. The interfaces to be considered for operations in the Workshop were those mentioned above, and in addition, Input Power, Data Output signal characteristics, (interface with vehicle data system), test subject work envelopes, lighting, etc. It was determined that the only interface requirements that could be satisfied within the scope of the program were the stowed (MDA) volume, mounting dimensions and the input power requirements. The information obtained on the other interface requirements was not lost, since the knowledge of these requirements and the known capabilities and limitation of the Task Panel have suggested various methods of satisfying the vehicle interface requirements.

Coupled with the efforts to establish the Task Panel/Vehicle interface requirements, efforts were instituted to integrate the requirements of several experiments so that a single Task Panel could be used for all. These experiments were: D020, Alternate Restraints Evaluation; M171, Metabolic Costs of Inflight Tasks; M507, Gravity Substitute Workbench; and M151, Time and Motion Study.

SECTION 5

EXPERIMENT DESCRIPTION

This section describes the experiment which was outlined in Section 3 and modified by the Feasibility Tests described in Section 4. The descriptions contained here refer to the conceptual Experimental Task Sequence presented in Section 3.

5.1 MAJOR EXPERIMENTAL CONDITIONS

5.1.1 RESTRAINT CONDITIONS

The entire experimental sequence is performed under three major restraint conditions. In the first case, a platform with the Gemini Dutch Shoes mounted on it provides a foot-anchoring restraint. The second restraint is a mechanically-operated, variable flexibility waist tether. The tethers are installed to the bulkhead by thumb-activated tapered pins on the distal end. (A prototype of the manually-operated unit was used for ground-based data collection.) The third restraint condition consists of a combination of the waist and shoe restraints.

An additional restraint is utilized in the experiment, but not as a major independent variable. A handhold is provided for use by the subject during installation of other restraints, removal of the task board cover and at various times during other tasks. The handhold contains a squeeze mechanism to activate attachment pins, which are installed in holes on the task board cover and on the Task Panel itself after the cover is removed.

5.1.2 PRESSURE SUIT CONDITIONS

The entire experiment sequence, including restraint installation, is performed under three suit conditions. They are the Apollo A7L (Block II) Suit, the Advanced Extra-Vehicular Suit (AES), and a no-suit (shirtsleeve) condition for IVA comparisons.

5.2 RESTRAINT INSTALLATION

An experiment session begins with the subject positioned in front of the worksite. All restraints are attached to the subject by lanyards--small cables on take-up devices. At a given signal, the subject proceeds to install his personal restraints.

In addition to his personal restraints, analysis leading to the definition of the task sequence indicated a need for equipment restraints to anchor tools, replacement parts, etc. Thus, this part of the sequence included installation of two equipment tethers, similar in procedure to installation of the waist tethers. Due to the unavailability of such equipment, however, this task was not performed during the ground-based data collection program.

5.3 GAIN ACCESS TASK

Having secured himself at the worksite, the subject now proceeds to remove and stow the protective cover on the task panel.

Tools were placed in a small holder atop the task board during ground-based data collection. Alternatively, the subject should be expected to carry a tool kit to the worksite.

During the ground-based data collection effort, it was discovered that the use of two different fasteners on the cover was superfluous and of marginal informational value. One set of fasteners was therefore deleted, resulting in a time saving of approximately 3-5 minutes. Also, since equipment tethers were not available, the subject simply handed the cover to an experiment technician.

5.4 INSPECTION, ACTIVATION AND CHECKOUT

The task sequence developed in Section 3.0 included a task to be representative of various inspection and checkout procedures commonly encountered. A task was detailed which included calibration of various modules (including the force/torque emission receiver), operational checkout of all electrical functions, status of operational maintenance task, and other steps. Ultimately, however, this task was eliminated from the experiment sequence.

5.5 TWO-HAND EYE/HAND COORDINATION TASK

This task requires the subject to perform steps representative of electronic equipment checkout and associated tasks. The subject uses a probe and, upon command, places it on one of three test points, which are designed to resemble a male electrical connector contact, a female electrical connector contact, and a printed circuit board solder joint. When contact is made, a digital display device displays a two-digit number. The subject must then set the analog device to the displayed number using coarse and fine potentiometers.

The task was repeated a total of nine times, so that each point is presented three times. The two-digit numbers are randomly selected.

One additional parameter is altered during this task: access condition. Nine trials are performed with no access restrictions, as described above. A limiting-access panel is then installed which restricts the subject's visual field and arm movements. Nine trials are then performed exactly as described above.

In all trials for this task, the subject is expected to maintain a firm contact with the test point. Broken contacts are indicated by an auditory signal.

5.6 PRECISE HAND MOVEMENT TASK

The Precise Hand Movement Task requires the subject to perform precise hand movements with varying degrees of difficulty and force emission requirements. This task does not directly simulate a spacecraft operational procedure but it does require the subject to perform a precise dynamic hand movement at different force emission levels. This type of task is inherent in many of the spacecraft EVA/IVA operational procedures and provides an excellent method for reliable and quantitative evaluation of restraint capabilities, suit performance characteristics and access envelopes.

The task consists of tracing an irregular, sawtooth path with three different tension loads on the probe - 1.25, 2.50 and 5.00 lbs. Constant tension loads are provided by the use of Negator Springs. As the path is traced, the tension cable also causes a signal to be generated which is proportional to the distance traced. A separate contact circuit between the path and the probe is provided for the top portion of the path and the bottom portion. Thus, it is possible to record not only the number of contacts made, but also precisely where each contact is made. The task was repeated for all three spring loads. When this was completed, a module removal and replacement task is performed by reversing the orientation of the precise hand movement module. The Precise Hand Movement Task is now repeated with the module in the new orientation, that is, with the springs at the subject's right. At the conclusion of these three trials, the module is reversed again to its original position.

Finally, all of the above procedures are repeated with the limiting access panel in place. Thus both the Two Hand Task and the Precise Hand Movement Task are performed under free and restricted access conditions.

5.7 FORCE EMISSION AND MODULE REPLACEMENT TASK

5.7.1 PROCEDURE

This task is designed to evaluate and quantify man's ability to generate impulsive, sustained and precise forces under various conditions of restraint, type of suit and force receiver location.

The three types of forces are defined as follows:

- Sustained - Subject exerts maximum force he can sustain from cue-signal ON to cue-signal OFF (4 seconds).
- Impulse - Subject exerts maximum possible instantaneous force upon receipt of cue-signal (signal remains ON for 2 seconds).
- Precise - Subject is required to match a commanded force value and maintain that value until cue-signal OFF (6 seconds).

5.7.1 PROCEDURE (CONTINUED)

Forces are applied through a D-handle mounted vertically on the shaft of the force receiver module. Forces are exerted in six directions: +X (Pull); -X (Push); +Y (Left); -Y (Right); +Z (Up); and -Z (Down). A panel directly in front of the subject provides cue indications. Twelve sustained and impulsive forces are presented in a randomized fashion. For each trial, the subject must perceive the cue, decide upon the force type and force direction, and exert the proper force. The cues are presented in this manner in order to provide a task in the sequence requiring a cognitive decision making analysis and response.

Precise forces are presented in separate blocks of six trials each and are random only with respect to direction. When a precise force is commanded, the subject is also given a force value which he must match. Two digital readouts -- one for the commanded value and one for the required force output -- provide a means of comparison. The commanded force values are given in Table 5-1. The values were selected to meaningfully tax subject capabilities, yet still be within the range of feasibility.

At the conclusion of these steps, the force receiver is moved to a new position in the upper right quadrant of the subject's reach envelope. This task constitutes a module removal/replacement task. The force emission task is now repeated at this new location. Thus, the force emission task comprises three force types and six force directions performed in two separate positions across the major experiment variables.

TABLE 5-1 COMMANDED PRECISE FORCE VALUES

DIRECTION \ RESTRAINT	WAIST	SHOE	WAIST & SHOE
PUSH	15.0 Lbs.	5.0	18.0
PUSH	15.0	5.0	18.0
LEFT	11.0	11.0	11.0
RIGHT	11.0	11.0	11.0
UP	11.0	20.0	24.0
DOWN	11.0	20.0	24.0

TABLE 5-1 COMMANDED PRECISE FORCE VALUES

5.8 TORQUE EMISSION TASK

During spaceflight maintenance and repair operations, man will be required to use tools to exert forces of various magnitudes. This task is designed to evaluate and quantify man's ability to generate impulsive and sustained forces utilizing tools under various conditions of restraint, type of suit and location of force receiver.

The conditions evaluated are similar to those in the Force Emission Task. The torque types are sustained, impulse and precise and are defined as before. Two positions are again evaluated -- a center position and a position in the lower left portion of the subject's reach envelope. Only two torque directions are evaluated--clockwise and counterclockwise about the force receiver center shaft.

Two different tools are used for torque emissions. One is an L-handle wrench which allows the subject to exert a true torquing force. The other is a T-handle wrench which requires the subject to exert a torsion-like motion.

Precise torques are performed similar to precise forces. The commanded values used are presented in Table 5-2.

TABLE 5-2 COMMANDED PRECISE TORQUE VALUES

TOOL \ RESTRAINT	WAIST	SHOE	WAIST & SHOES
T-HANDLE			
CW	25.0 In.-Lb.	25.0	25.0
CCW	25.0	25.0	25.0
RATCHET			
CW	60.0 In.-Lb.	120.0	144.0
CCW	60.0	120.0	144.0

TABLE 5-2 COMMANDED PRECISE TORQUE VALUES

5.9 OPERATIONAL MAINTENANCE TASK

The Operational Maintenance Task requires the subject to remove and replace a component from a gas plumbing system when the assembly has "failed". The task is activated by a control switch on the observer's panel. This switch causes a solenoid valve on the task panel to operate which results in dumping the pressure in the system. A meter on the panel will indicate the pressure drop, and a warning signal - consisting of a flashing light and an auditory alarm - will be activated. The subject is expected to recognize the failure and proceed with the corrective action.

5.10 CONCLUDING TASK

The remainder of the task sequence was designed to simulate required operations that would successfully conclude any EVA/IVA task. Thus, the subject is required to return the cover to the Task Panel and install it. When this is completed, the subject removes his personal restraints, fastens then to lanyards and to suit tie-down, and leaves the worksite.

SECTION 6

DATA COLLECTION ACTIVITIES

Four ground-based simulation techniques were utilized to collect the data required to satisfy the objectives of the experiment. These techniques involved three zero-gravity simulation methods as well as performance of the experiment in the one-gravity environment. For ease of writing, the one-gravity data collection is also considered to be a ground-based simulation technique.

The one-g and neutral buoyancy simulations were performed at the Controlled Buoyancy Facility, located at the General Electric Space Division Complex at King of Prussia, Pennsylvania. The 6 Degree-of-Freedom mechanical simulations were performed at the NASA, Marshall Space Flight Center utilizing their Action-Reaction Free Fall Simulator. The final mode of zero-gravity simulations was the Keplerian Trajectories performed in the KC-135 aircraft supplied by the Aeronautical Systems Division at Wright-Patterson Air Force Base, Dayton, Ohio.

The following paragraphs in this section describe the details of the data collection activities and instrumentation and data recording equipment associated with each of the simulation modes.

6.1 INSTRUMENTATION AND DATA RECORDING

The instrumentation for the ground-based data collection effort was designed to provide a permanent record of the data gathered during the test programs and provide the capability for data reduction and analysis on a non-real time basis. Figure 6-1 illustrates the test set-up used in all four simulation test modes.

The signal conditioning equipment contained in the Electronics Box was described in Section 4.2. The equipment described here provided the interface between the Electronics Box and the data collection and recording equipment.

An eight-channel oscillographic recorder (Brush Mark 200) was used for data recording, since no more than eight signals were necessary for display or recording during any one task. Depending on the task being performed, the test director changed the signal inputs to the recorder by using small patch boards which could quickly and easily be changed during subject rest periods. The recorder was situated in close proximity to the test director to provide a real-time display of the operational status of all telemetry signals.

The Brush Mark 200 recorder was not suitable for use aboard the KC-135 0-g aircraft. Hence, for that mode only, a GFE, 24-channel Visicorder was used.

6.2 ONE-G DATA COLLECTION ACTIVITIES

The one-g test series was conducted at the GE Valley Forge Facility. In order to utilize the same instrumentation and recording equipment as the neutral buoyancy tests, the one-g testing was done adjacent to the Controlled Buoyancy Facility.

The total experiment required the performance of 36 sessions to complete the condition combinations of restraints, suits, subjects and replications. The one-g

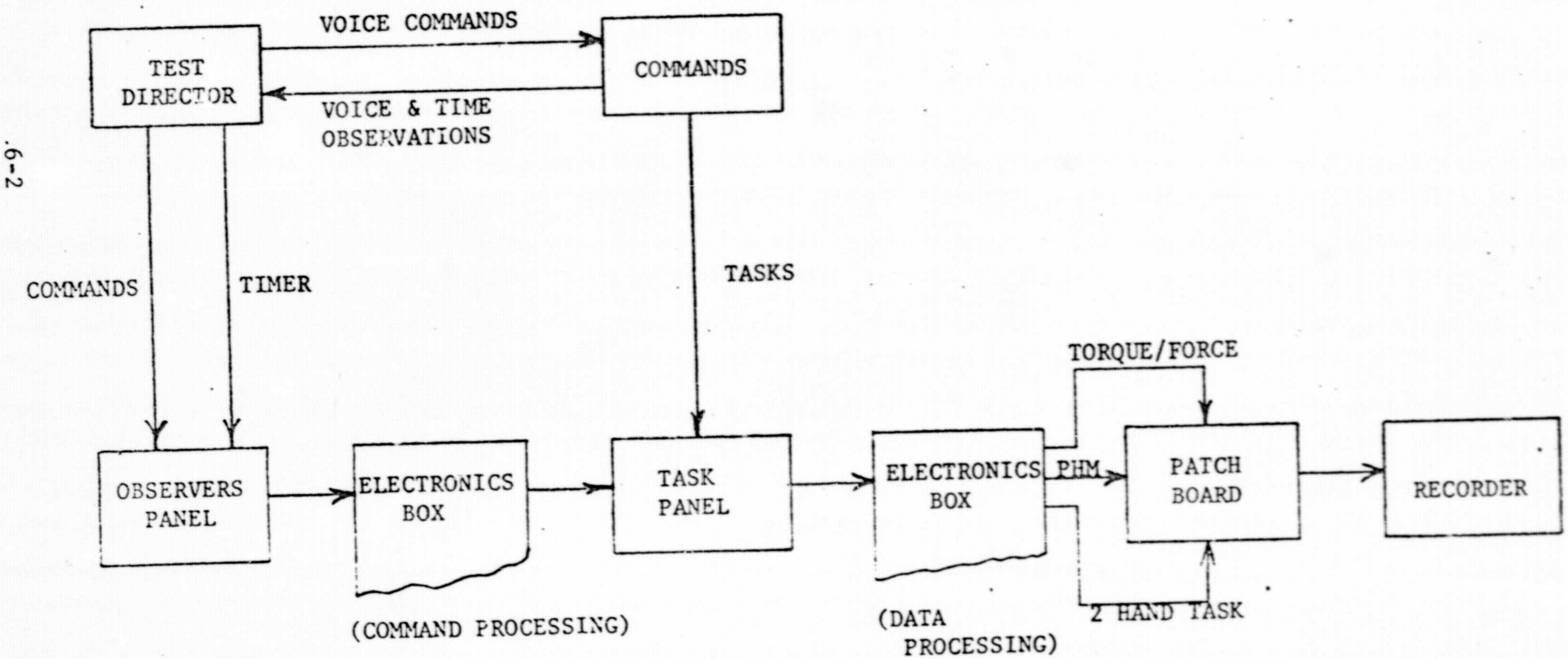


FIGURE 6-1 DATA COLLECTION TEST SETUP

6.2 ONE-G DATA COLLECTION ACTIVITIES (Continued)

testing reduced the 36 sessions to 24 because the waist restraint only condition was impossible in this mode. The 24 remaining sessions evaluated two restraint conditions (shoes only and waist and shoes), 3 suited conditions (Shirtsleeve and 2 Suits), and 2 subjects with each condition replicated.

The suits used were an A6L, Medium Long and an A7L, Large Long. The Litton Advanced Extravehicular Suit was comparable in size to the Apollo, Large Long and had enough built in adjustment capability to accommodate the subject who wore the A6L suit.

Data collection during the one-g testing was accomplished by recording the outputs of the task panel. Comments applicable to the test were identified on the chart paper, and also logged in the session instruction sheets. Photographic data was collected using a Mauer 16 mm camera at 8 frames/sec.

6.3 ACTION-REACTION FREE-FALL SIMULATOR (6 DEGREES-OF-FREEDOM)

This test series was performed at the Marshall Space Flight Center, Huntsville, Alabama. The action-reaction free-fall simulator was developed by the Manufacturing Engineering Laboratory at MSFC for the purpose of determining the design integrity of space-oriented equipment. Naturally, this simulator cannot prevent the test subject from feeling the gravitational pull as it forces him against the harness straps. In order to simulate a believable zero-gravity condition, the test subject and the simulator must be considered as one entity. In this way, the six degree-of-freedom, action-reaction, zero gravity phenomena can be observed.

The number of tests planned in this mode was minimized by eliminating the replication of each session. This effectively reduced the test plan from 36 to 18 sessions, thus collecting data on 2 subjects across 3 suits across 3 restraints. Further reduction of the test plan was later realized when the AES suit would not conform to the simulator harness assembly. The major problem area was the cycle seat, which would not permit the legs to come together, thereby eliminating the opportunity to utilize the shoe restraint. In addition, the full potential of the suit could not be realized because of the harness and waist restraint restricting the suit mobility.

Data collection and film coverage during this series was identical to the one-g simulation.

6.4 NEUTRAL BUOYANCY

The facility used for the conduct of the neutral buoyancy simulation portion of the experiments is a part of the General Electric Space Division Complex located at King of Prussia, Pennsylvania. The facility is designated the Controlled Buoyancy Facility and consists of the pool area, locker and shower rooms, experiment preparation area, pressure suit storage and drying area, experiment control area, medical/first aid area, and peripheral pool support equipment and shops.

6.4 NEUTRAL BUOYANCY (Continued)

The test plan for the neutral buoyancy testing was revised in the following manner. By eliminating the Apollo A7L suit, from the underwater activities, the neutral buoyancy test plan was reduced from 36 sessions to 24 sessions. Further reduction in the test plan resulted from delays associated with equipment and pressure suit failures and subject illness during the underwater portion of the program. The Task Panel is the most intricate equipment ever operated in the G.E. underwater facility, consequently, unforeseen problems developed which were resolved but without undue loss of valuable testing time.

The pressurization system for the neutral buoyancy simulation program consisted of the air bank, 2 stage regulator, backpack, surface flowmeter, and pressure gage. The backpack was originally designed and developed by the General Electric Company as a water pressurization device to be used in conjunction with a specially designed quick-disconnect helmet. The backpack compensates for pressure differentials as the subject descends to working depth. However, the pressure could also be controlled manually by the safety diver to assist the subject's ingress and egress. The air flow rate and pressure were maintained at 10 cfm and 3.5 psi (gage) respectively and continually monitored on the surface to insure the safety of the subject.

Each subject was neutrally buoyed at the start of each experiment session. Lead weights were added as required to the weight harness, to adjust for the individual subject's weight and center of gravity. The weight harness, approximately 130 pounds, not only compromised the mobility of the suit, but also had a very fatiguing effect on the subjects during ingress, egress, weight attachment and neutrally buoying.

The shirtsleeve sessions utilized a standard scuba regulator attached to a hookah line. A simple back-mounted harness consisting of a shoulder harness worn over the thorax was used to maintain the regulator hose at a fixed position. Neutral buoyancy was obtained by adding weights or flotation material to the subject prior to each experimental session.

6.5 KC-135 ZERO GRAVITY

This portion of the test program was performed at Wright-Patterson Air Force Base with the support of the Aeronautical Systems Division (ASD). The testing was conducted during weightless simulation flights using the Air Force KC-135 Zero-G test aircraft. In these flights, the aircraft followed a ballistic trajectory so that objects insidesthe aircraft were in a state of free-fall, thus being effectively weightless. The period of weightlessness produced was nominally 25 seconds. The degree of accuracy was $\pm$ .01G and depended primarily on pilot profiency and prevailing weather conditions.

The test plan for this portion of the program had to be drastically modified to accommodate the limited time available aboard the aircraft. In order to accomplish this, the number of sessions and the time required for each session had to be reduced. The test plan of 36 sessions was reduced to 18 by eliminating each replication, and the time-line for each session was reduced by eliminating the following tasks:

1. Foot restraint installation
2. Cover removal
3. Installation of access panel
4. Removal of access panel
5. Cover replacement

Seven reduced time-line sessions requiring approximately 55 parabolas per session were completed during the 2 weeks in which the aircraft was available for the program. The aircraft made 8 flights and accumulated a total of 375 parabolas.

The suit pressurization system was identical to the one-g system, utilizing an air bank and the AAP controller.

Complete recalibration of the output circuitry in the electronics was required to use the Visicorder available on the aircraft. The Visicorder is a 24 channel recording instrument that utilizes light sensitive paper rather than ink and it is not affected by the zero-gravity maneuver.

SECTION 7

DATA ANALYSIS AND RESULTS

7.1 DATA REDUCTION AND COMPUTATION PROCEDURES

This section describes the technique utilized to convert the raw data resulting from the data collection activities described in Section 6 into the measures defined in Section 5. All voltage data was read and manually converted to engineering units. The converted data was then tabulated on computer-compatible formats. Five basic task divisions were identified: Two-Hand Data, Precise Hand Movement Data, Precise Force Data, Impulse and Sustained Force Data and Torque Data. The sixth format was used to tabulate task-time data. These divisions were established mainly for ease of analysis and consistency of computational techniques required. For each of the five categories, a computer program was written to permit analysis on the GE-605 Desk-Side Time-Shared (DSTS) computer system. This method of analysis allows the experimenter to use the data bank in a "conversational mode", combining various data points in ways that permit comparisons about performance parameters across different combinations of experimental conditions.

Conversion of the information contained on the data sheets to useful performance measures was accomplished by writing separate computer programs for each of the five data divisions, plus a sixth routine which is used to set input conditions for the analysis. The data was transferred to punch cards and then to permanent disc storage on the GE-605 Desk-Side Time-Sharing System. The programs provide the analyst with the capability to select the desired task and to average data points across different combinations of subjects, simulation modes or other experiment variables.

7.2 RESULTS AND CONCLUSIONS

The performance measures which resulted from the computation program were analyzed with three specific objectives. First, it was desired to analyze each task to determine whether or not it reliably and meaningfully differentiated between major experimental conditions. Second, performance measures were studied to discover any meaningful trends which, even without actual flight validation, provided useful information about the experimental conditions. Finally, performance measures were studied to discover design data suitable for inclusion in a handbook of human performance data.

To assess the significance of the results, the data were subjected to a statistical analysis. Non-parametric techniques were utilized for the analysis because of the small sample size involved and because of the inability to make accurate predictions about the nature of the distributions underlying the data. The primary requirements for non-parametric analyses are that the observations be independent and that the variables have some underlying continuity. In such cases Siegel, 1956, recommends two tests of significance which were useful here. The Wilcoxon Matched Pairs Signed Ranks Test is applicable where observations corresponding to two levels of an independent variable have been collected (such as in testing whether there is a significant difference in performance between two subjects). The Friedman Two-Way Analysis of Variance is applicable where there are observations corresponding to three or more levels of an independent variable.

7.2 RESULTS AND CONCLUSIONS (Continued)

The main disadvantage of the above tests is that they are not influenced by the magnitude or the direction of different performances. They do not, for example, indicate whether subject 1 consistently performed "better" than subject 2, but only that the two subjects' performance was different. Subjective interpretation of performance means must therefore be used to determine the physical importance of performance differences.

Each task and its associated measures are analyzed below utilizing these techniques.

7.2.1 PRECISE HAND MOVEMENT TASK

Table 7-1 summarizes the results obtained for the Precise Hand Movement Task. The numerical entries in the table are mean scores across all experimental variables other than the variables of interest. Thus the entries under "MODES" represent averages for the different spring tensions, access conditions, orientations, subjects, and so forth.

The only measures listed in Table 7-1 are traverse time and number of contacts. Percentage time spent in contact did not provide any significant information in addition to the information provided by these two measures.

The significance of the results is summarized below for each variable:

MODES - Statistically significant different performances occurred across the four simulation modes for both the time measure (significant at the level .005) and the accuracy measure (.01 level). The KC-135 simulation resulted in a much faster time than the other modes, a "hurry-up phenomenon which occurred consistently across all tasks. Paradoxically, however, the fewest number of contacts also occurred in the KC mode. This contradicts expectations, which imply that accuracy and traverse time should be inversely related. The results listed imply a direct relationship. The 1-g mode results were consistently slower and less accurate than the three 0-g simulation modes. This implies that the ability to exert precisely controlled hand movements is enhanced by the zero gravity environment when restrained at a worksite.

SUITS - Performance scores for both measures were statistically different at a .005 level of significance. Suited performance was 18% slower and 25% more inaccurate than shirtsleeve performance, representing a comparison of IVA vs. EVA performance of a dynamic, precision task. Differences in performance scores between the two suits were not large enough to be meaningful.

RESTRAINTS - Restraint differences were significant at a .05 level for traverse times and a .005 level for contacts. However, for both measures, the magnitude of the difference is less than 10%. This probably results

TABLE 7-1

RESULTS SUMMARY - PRECISE HAND MOVEMENT

VARIABLE		TRAVERSE TIMES		NO. OF CONTACTS
MODES	1-G	14.2 Sec.		10.06
	NBS	12.5		*
	6 DOF	12.3		9.49
	KC-135	9.6		8.50
SUITS	SS	11.74		8.36
	A7L	13.34		10.56
	AES	14.36		10.38
RESTRAINTS	W	12.08		10.70
	S	13.05		9.00
	W&S	12.96		10.06
ACCESS	Free	12.59		6.84
	Lmtd.	12.94		9.86
ORIENTATION	Left	12.94		8.44
	Right	12.54		8.25
SPRINGS	1.25 Lb.	12.23		7.44
	2.50 Lb.	12.64		8.42
	5.00 Lb.	13.41		9.15
LOCATION OF CONTACTS			Top	3.67
			Bottom	4.68

*Data not recorded.

7.2.1 PRECISE HAND MOVEMENT TASK (Continued)

RESTRAINTS (Continued) - from the fact that when the limited access panel is in place, subjects had to use the handhold for support. They were, therefore, instructed to use the handhold when the access condition was free (to permit comparison). As a result the restraints here are not really waist, shoes, and waist and shoes, but hand and waist, hand and shoes, and hand, waist and shoes.

ACCESS - Performance differences between the two access conditions were significant at the .05 level. For traverse time, the magnitude of the difference was less than 3%. But in terms of accuracy, a 43% degradation occurred when the access was restricted. This implies a serious problem in terms of precision when an astronaut is expected to work through a small access port.

ORIENTATION - Differences in performance for the two module orientations were small (less than 3%) and considered to be not meaningful.

SPRINGS - Although a statistically significant difference in performances occurred for the three springs, the differences seem completely attributable to the increase in spring tension. No particularly meaningful information is provided by these differences.

LOCATION OF CONTACTS - More contacts occurred on the bottom of the path than on the top. This is probably simply a result of the geometry of the situation - the subject's hand blocked his view of the bottom edge - and is not considered important.

In summary, the Precise Hand Movement Task differentiated significantly and importantly between different simulation modes and between shirtsleeve and suited conditions. In addition, an important problem associated with restricted access tasks was discovered.

Task Recommendations: The task procedure may be simplified by

- o Using only one module orientation
- o Using only one spring tension

The task telemetry may be reduced to only

- o Total traverse time
- o Total number of contacts

Contact location or duration need not be recorded.

7.2.2 TWO-HAND TASK

Table 7-2 summarizes the results obtained for the Two-Hand Task. Again, the table entries are mean scores across all variables other than the variable of interest. The significance of the results is summarized below for each variable:

TABLE 7-2

RESULTS SUMMARY - TWO-HAND TASK

VARIABLE		TRIAL TIMES	RESPONSE TIMES	SETTING ERRORS*
MODES	1-G	36.7 Sec.	3.39 Sec.	.77
	NBS	21.9	2.32	1.09
	6 DOF	35.8	3.41	1.28
	KC-135	29.1	2.96	.65
SUITS	SS	28.6	2.56	.80
	A7L	35.6	3.32	.77
	AES	38.3	3.89	1.29
RESTRAINTS	W	32.7	3.21	1.11
	S	33.6	3.21	.93
	W&S	32.3	3.05	.83
ACCESS	Free	32.2	3.09	.97
	Lmtd.	33.9	3.21	.84
TEST POINTS	M	31.0	3.01	.88
	F	33.1	3.35	.90
	S	35.0	3.09	.95

*Mean absolute deviation from command.

7.2.2 TWO-HAND TASK (Continued)

MODES - All three performance measures exhibited statistically significant differences across modes at the .005 level. As in the Precise Hand Movement Task, trial times differed greatly in the different simulation modes. The KC-135 aircraft simulation total time was not the fastest, but it was about 20% faster than either the 1-g or 6 DOF results. The differences in response times and setting errors, though large in some instances, were not felt to be of any intrinsic value. The important conclusion is that a simulation effect upon performance does exist and this task, as measured by total trial time, will denote this effect.

SUITS - Performance differences across suit conditions were statistically significant at the .01 level for trial times and setting errors and the .005 level for response times. Moving from a shirtsleeve (IVA) to a suited (EVA) condition increased trial time 30% and response time 40%. In addition, this task indicated a 10% increase in trial time and a 15% increase in response time when wearing the AES suit as opposed to the A7L suit.*

The 65% increase in the magnitude of the setting errors between the AES and the two other suit conditions reflects an important visual problem noted by the subjects. Viewing through the AES suit helmet at the downward angle required to see the voltage meter, a small visual distortion was noted by both subjects and confirmed by this data. This problem is further substantiated if this data is broken out for the two access conditions: the difference is smaller in the limited access condition (where the subject looks through the opening and therefore at a more horizontal viewing angle) than in the free access condition (where the subject looks down at about a 30-45 degree angle).

RESTRAINTS - The three measures noted did not reveal any important differences regarding the three restraint conditions. Apparently, for a static task of this nature, any relatively stable, one-point restraint is satisfactory.

ACCESS - No important performance differences were noted for this variable. The limited access condition did not degrade performance for this <u>static</u> test of accuracy as it did in the <u>dynamic</u> accuracy required by the Precise Hand Movement Task.

TEST POINTS - Some minor performance differences can be noted for the three different test points, but they were not felt to be of any important value.

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*It is important to realize that these tasks, limited only to performance at a worksite, do not really constitute a suit evaluation. Nevertheless, important performance differences that were noted deserve special mention.

7.2.2 TWO-HAND TASK (Continued)

In summary, the Two-Hand Task differentiated significantly and between different simulation modes and between shirtsleeve (IVA) and suited (EVA) conditions. In addition, for a precision, static task, it was discovered that a relatively stable one-point restraint of any type is satisfactory, and tha the existence of a restricted access (similar to the restriction used in this experiment) does not degrade performance of such a task.

Task Recommendations: The experiment procedure may be simplified by:

- Using only one test point.

Although further simplification can be gained by using only one restraint condition and one access condition, it is recommended that these variables be retained. They are necessary for other tasks and therefore represent no real increase in complexity for this task. The time savings in their deletion would be small (only about 1 minute per session) and their retention would allow a chance to confirm the findings here concerning performance of static, precision tasks.

The task telemetry may be simplified by eliminating:

- Number of broken contacts.
- Duration of broken contacts.

These measures provided no meaningful information.

7.2.3 PRECISE FORCE TASK

Table 7-3 summarizes the results of the Precise Force Task. The table entries have the usual interpretation and represent the mean absolute deviation of the average force exerted from the commanded force.

There is a critical assumption that should be noted when data from different restraint conditions and different force directions are averaged together. Since the commanded value for these different conditions vary, it is assumed that the three commands present about the same level of stress and complexity to the subjects. This is a reasonable assumption, since the values were selected from previously-collected force emission data using the same selection criteria for each combination of restraint and force direction. The assumption, of course, can not really be verified.

The results are summarized below for each major experimental condition:

MODES - Performance differences were statistically significant at a very high level (.005). There was a very large degradation (3 to 1) in precision force emission capability in the KC simulation compared to the 1-g simulation.

TABLE 7-3

RESULTS SUMMARY - PRECISE FORCE TASK

VARIABLE		MEAN ABS. DEV. FROM CMD.
MODES	1-G	1.56 Lbs.
	NBS	3.40
	6 DOF	2.31
	KC-135	4.59
SUITS	SS	2.91
	A7L	2.50
	AES	2.88
RESTRAINTS	W	4.86
	S	2.03
	W&S	2.74
POSITIONS	Center	2.52
	Upper Right	3.08

7.2.3 PRECISE FORCE TASK (Continued)

SUITS - No statistical or practical differences occurred across the different suit conditions.

RESTRAINTS - Restraint differences were significant at a .05 level. More importantly, this task indicated a phenomenon that occurred in all tasks where the restraint was critical to task performance. As expected, the waist restraint was not as good a restraint as either the shoe or waist and shoe combinations. But, perhaps surprisingly, the waist and the shoe combination restraint degraded performance. That is, the scores with the waist and shoe combination restraint deviated more from the commanded value than they did for the shoe only restraint. This is not an isolated effect, as it occurred in all force and torque tasks. The conclusion to be drawn is that a shoe-only restraint is more effective than when it is combined with this particular waist restraint, even though the latter represents a two-point body-anchoring system.

POSITIONS - A 20% performance degradation occurred when the force receiver was moved from the center to the upper right position. While this alone is not indicative of any problems with the major experimental variables, it does provide objective quantification of a useful performance parameter.

Interestingly, the performance degradation was well over 20% in the waist and waist and shoe restraint conditions, but almost negligible in the shoe restraint only condition.

In summary, the Precise Force Task differentiated significantly and meaningfully between the different simulation and restraint conditions. Once again, a simulation effect is definitely influencing performance. The inadequacy of the particular waist restraint used showed up clearly (as it will in other tasks).

Task Recommendations: No changes are recommended for this task.

7.2.4 SUSTAINED AND IMPULSE FORCE TASK

Table 7-4 summarizes the results of the sustained and impulse force task. Note that no data is reported for the KC simulation. During data analysis, the average forces for this mode were discovered to be 50% higher than for the 1-g mode (inconsistent with the pattern displayed by the other modes) and almost twice as high as the average forces recorded in the other zero-g simulations. Although it could not be checked, the data were rejected on the assumption that the flight recorder was not functioning properly. It is entirely plausible to assume that this data is unreliable while still accepting the data for the precise force trials and for the torque trials (which were not at all consitent with the behavior of this data). In these cases, the force and torque emissions would correspond to the lower 1/3 of the 5-volt telemetry signal range. But in

TABLE 7-4

RESULTS SUMMARY - SUSTAINED, IMPULSE FORCE TASK

VARIABLE		SUSTAINED(FIN)	IMPULSE(MAX)
MODES	1-G	53.4 Lbs.	89.1 Lbs.
	NBS	26.0	86.4
	6 DOF	29.2	66.6
	KC-135	---	---
SUITS	SS	38.1	89.1
	A7L	42.8	88.9
	AES	38.8	84.1
RESTRAINTS	W	18.4	75.0
	S	41.3	91.8
	W&S	46.4	88.9
POSITIONS	Center	43.1	91.1
	Upper Right	36.0	84.8

the sustained and impulse force trials the signals would correspond to the upper 1/3 of the telemetry range. If the difficulty in this task were associated with recorder malfunction at the higher voltages, it would be noticed only in this task. Most other telemetry consists of the "ON-OFF" type of signal where the height of the signal is of no concern.

Because of the value of force emission data to spacecraft designers and mission planners, the force data is presented in Figure 7-1.

The results are summarized below for each major experimental condition:

MODES - Performance differences across simulation modes were statistically significant at the .005 level for Sustained forces and the .01 level for Impulse forces. As should be expected, the degradation for sustained forces was much more serious than for impulse forces. The simulated zero-g modes(NBS and 6 DOF) displayed approximately a 50% reduction from the one-g sustained force emission capability. However, the degradation of impulsive force generating capability as a function of going from the one-g to the simulated zero-g mode was not nearly so severe. The almost 2.5 to 1 increased capability to exert impulse forces over sustained forces in the NBS and 6 DOF simulations is consistent with test results obtained from previous studies.

This task pointed out an interesting difficulty with 6 DOF simulation. Unlike other simulation modes, when the subject's body reacted to a force emission, not only was it necessary for him to regain control of his body, but he also had to stop the movement of the entire free-swinging 6 DOF apparatus. The momentum of this rig can make regaining control a difficult task. The potential result is that some part of the subject's body or the rig may collide with the supporting structure, either injuring the subject or damaging the equipment. The hypothesis here is that this potential is apparent to the subject and causes him to ease up in his task performance. Support for the hypothesis is found in a direction-by-direction comparison of impulse forces. In the right, left, up and down directions force emissions were much greater (20-50%) in NBS than in 6 DOF. In the Push-Pull directions(where body reaction is straight back and forth and where the waist restraint essentially stops backward reaction to a push force) the effect is not as noticeable. In sustained forces, where body reaction is not so violent, the effect is also not as noticeable.

SUITS - Different suit conditions did not affect force emission capability.

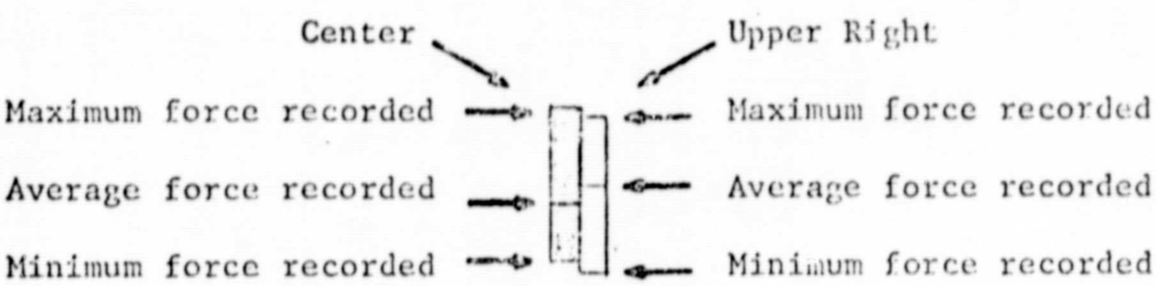
RESTRAINTS - Performance differences were statistically significant at the .01 level for sustained forces, but not significant for impulse forces. The practical significance of these differences again indicated that the waist restraint combined with the shoe restraint results in a degradation of performance. This result did not appear in the Impulse forces, where, as the statistical test shows, restraint conditions did not really affect performance.

INSTRUCTIONS FOR USE OF FIGURE 7-1

The next six pages contain summary data of the sustained and impulse force task. The data are presented for the one-g case and for a simulated 0-g case which consists of the average of data from the 6 DOF and Neutral Buoyancy simulations. It was deemed necessary to present average data for these two simulations since neither case alone is necessarily representative of the true 0-g situation.

The data are presented using a vertical bar-graph format, which is interpreted as follows:

FORCE RECEIVER POSITION



"Center" refers to a position where the force receiver handle is located directly in front of the subject's right nipple; "upper right" locates the handle about 15" above and 6" to the right of the center position. All other experimental conditions are clearly labeled on the chart.

FORCE TYPE: SUSTAINED

SUIT CONDITION: SHIRTSLEEVE

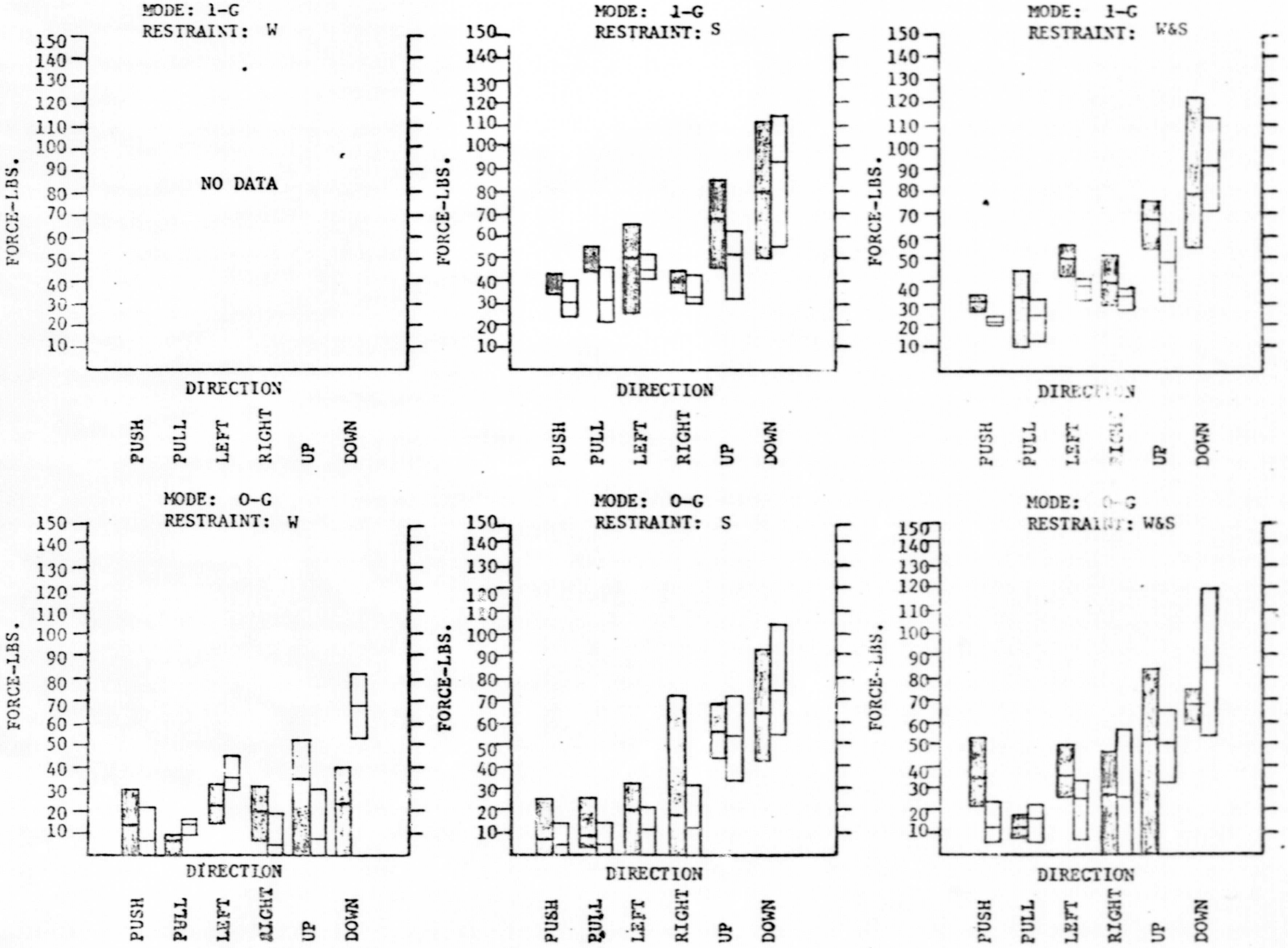


FIGURE 7-1 SUMMARY DATA CHART NO. 1

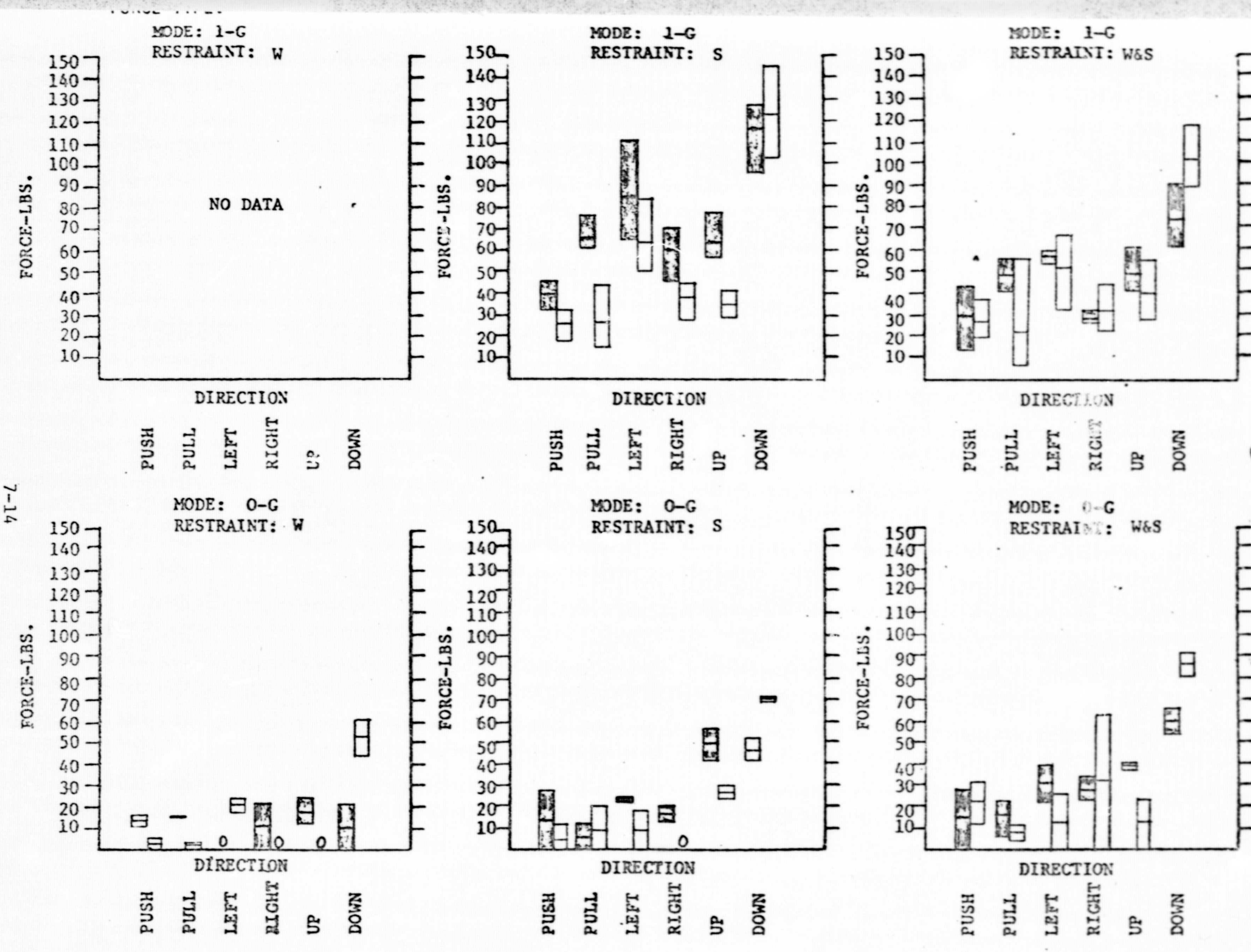


FIGURE 7-1 SUMMARY DATA CHART NO. 2

FORCE TYPE: SUSTAINED

SUIT CONDITION: AES

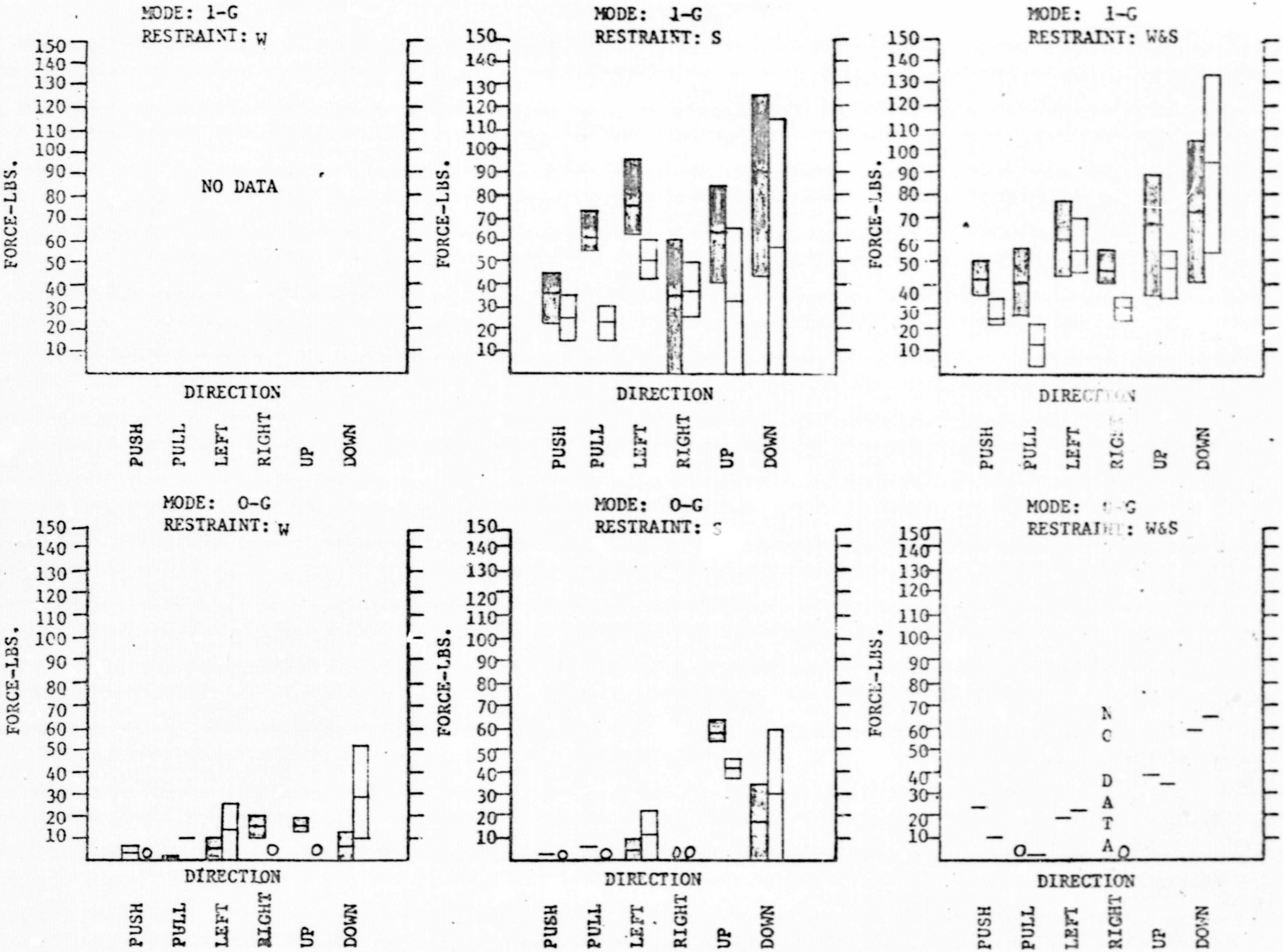


FIGURE 7-1 SUMMARY DATA CHART NO. 3

FORCE TYPE: IMPULSE SUIT CONDITION:

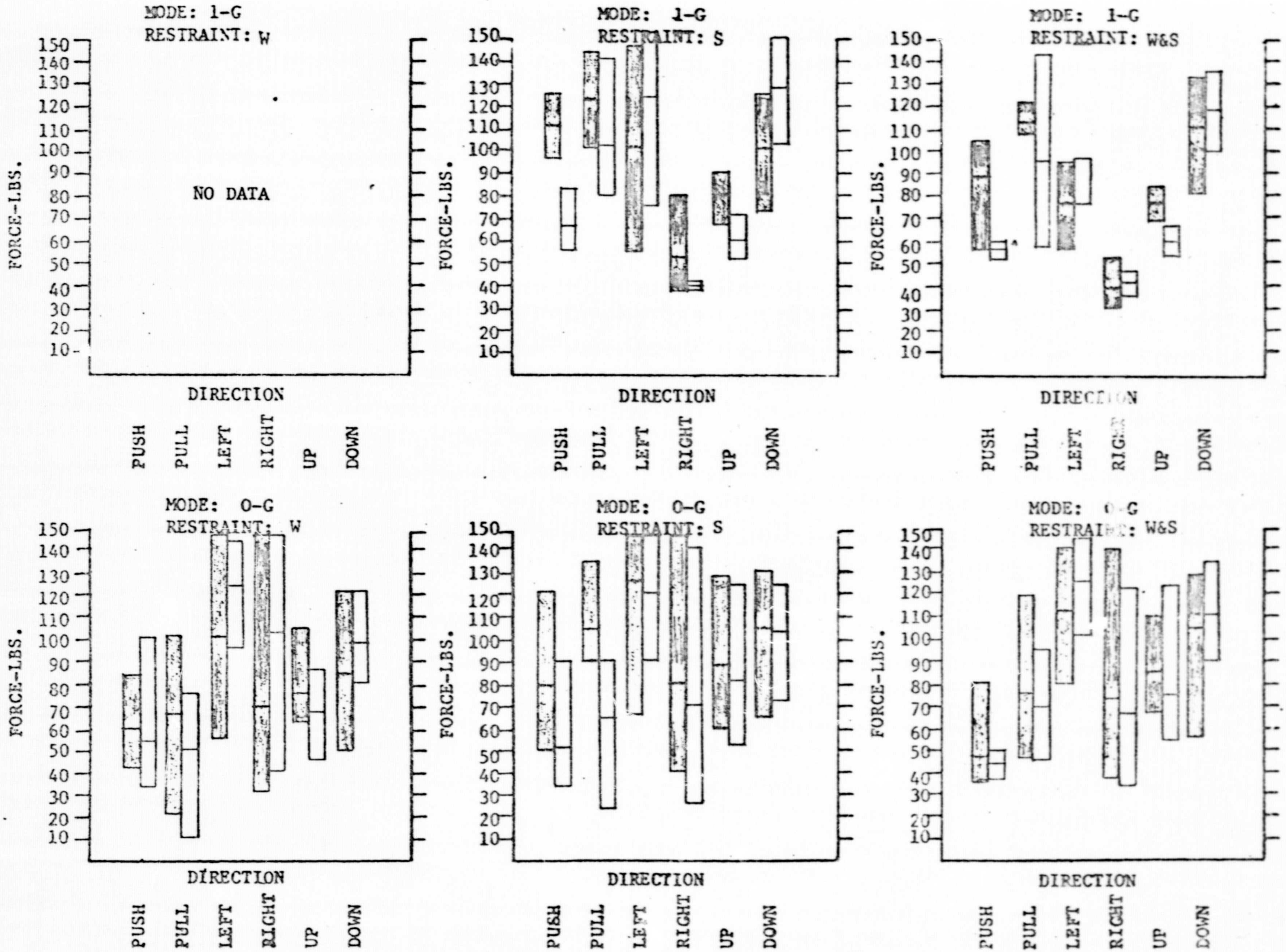


FIGURE 7-1 SUMMARY DATA CHART NO. 4

FORCE TYPE: IMPULSE SUIT CONDITION: A7L

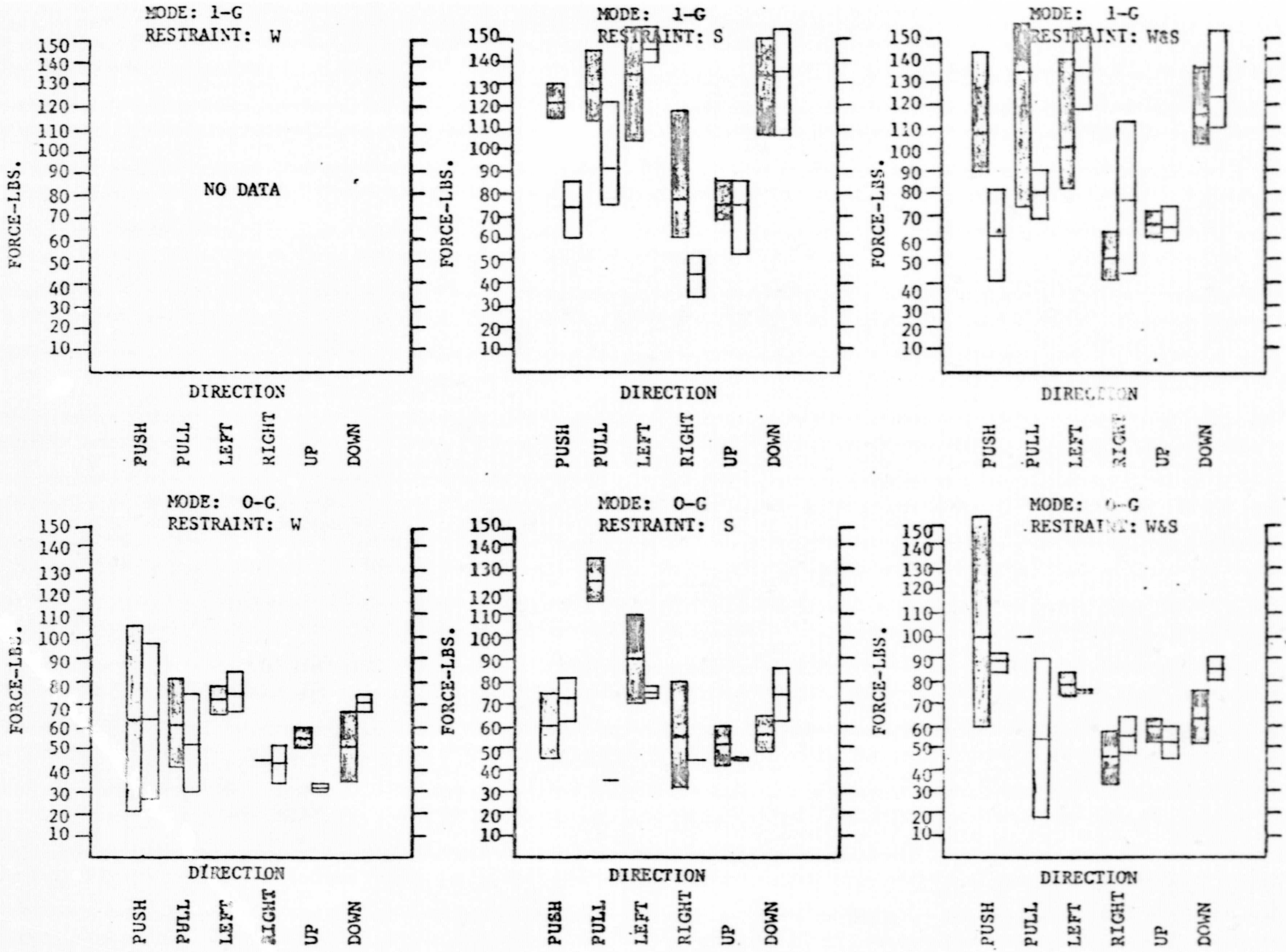


FIGURE 7-1 SUMMARY DATA CHART NO. 5

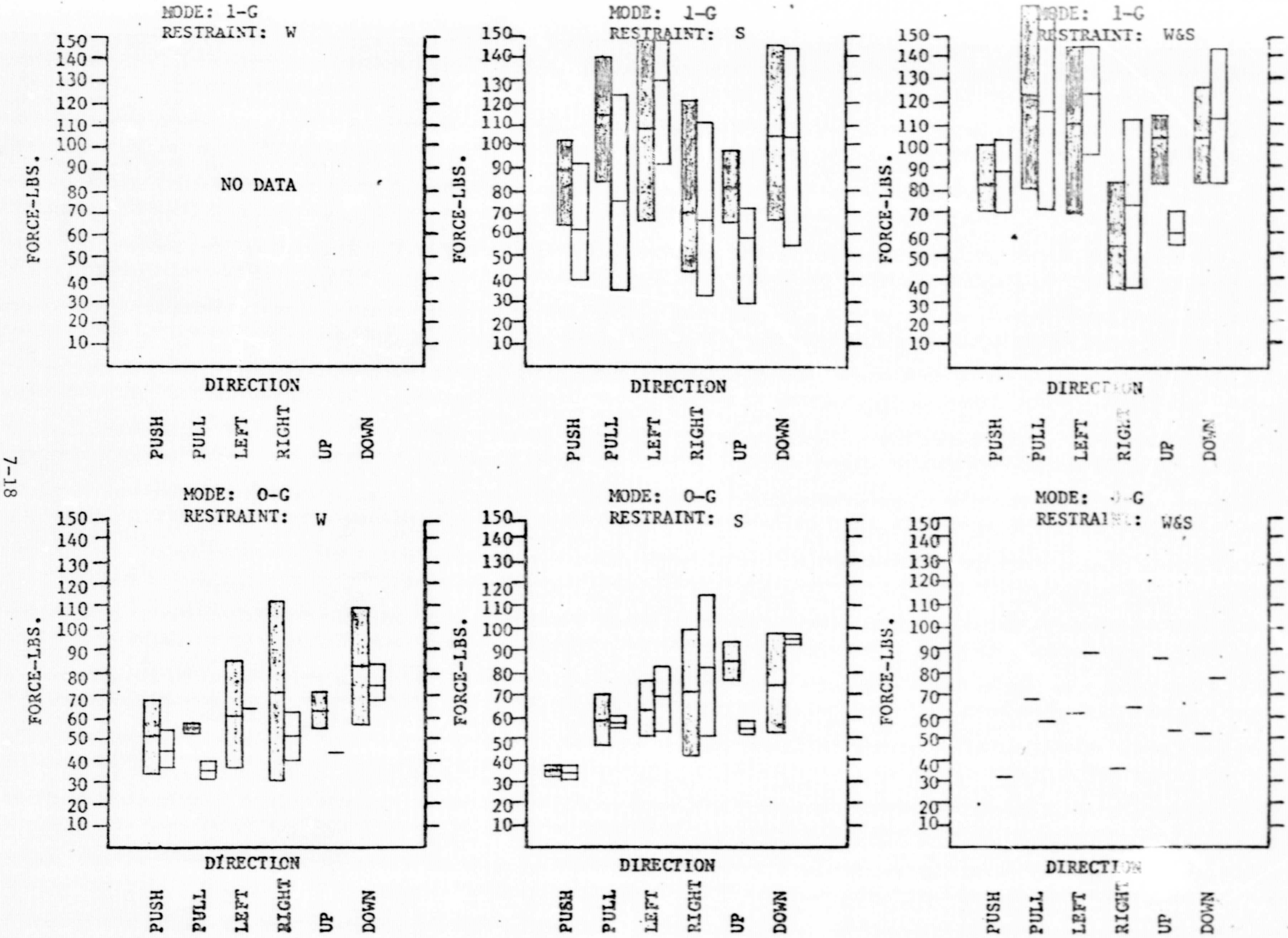


FIGURE 7-1 SUMMARY DATA CHART NO. 6

7.2.4 SUSTAINED AND IMPULSE FORCE TASK (Continued)

POSITIONS - As in precise forces, a consistent performance degradation was noted when the force reciever was moved to the upper right position. These measures quantify this degradation as an astronaut works in a less-than-optimal position in the reach envelope.

In summary, this task presented further substantiation of simulation and restraint effects upon performance. An additional conclusion noted from this task was the existence of much slower (30%) response times in zero-g simulations than in the 1-g case.

Task Recommendations: No major changes are recommended for this task. It is suggested, however, that FIN (for sustained forces), MAX (for impulse forces), and response time are the only necessary measures, as other measures present only redundant or superfluous information.

7.2.5 PRECISE TORQUE TASK

The results for the Precise Torque Task are summarized in Table 7-5 and below:

MODES - Performance differences across modes were not statistically significant. However, large differences in magnitude were noted with 25 to 100% increase in deviations when going from the 1-g to the simulated zero-g modes.

SUITS - Performance differences across suits were statistically significant at the .05 level. The differences are large, but no strong conclusions can be drawn, particularly since the differences were not consistent with those found in the Precise Force Task. However, it should be noted that the mean deviations increased approximately 40% when going from the shirtsleeve to the suited conditions.

RESTRAINTS - Performance differences across restraint conditions were not statistically significant. However, once again, it is noted that the shoe restraint alone is better than the waist and shoe combination, both of which are better than the waist restraint only.

POSITIONS - A degradation in precise torquing performance is noted when the force receiver is moved from the center to the lower left position. This difference could not be tested statistically using the tests described previously. The large difference (approximately 20%) is probably due in part to the fact that the precise readout meter is no longer directly in front of the subject.

TOOLS - The different performance for the two tool conditions also could not be tested statistically. Howeve the results are not unlike what should be expected for these conditions and indicate a 40% degradation in exerting precisely controlled torques when going from a T-handle to an L-handle lever arm.

TABLE 7-5

RESULTS SUMMARY - PRECISE TORQUE TASK

	VARIABLE	MEAN ABS. DEV. FROM CMD.
MODES	1-G	7.5 In. Lbs.
	NBS	14.8
	6 DOF	9.4
	KC-135	10.3
SUITS	SS	7.8
	A7L	11.4
	AES	10.5
RESTRAINTS	W	11.0
	S	8.5
	W&S	9.9
POSITIONS	Center	8.6
	Lower Left	10.5
TOOLS	L-Handle	11.1
	T-Handle	8.0

7.2.5 PRECISE TORQUE TASK (Continued)

In summary, this task presented some meaningful results. However, these results add nothing to those already found in the Precise Force Task and in the other tasks. All of the experimental conditions evaluated here are evaluated elsewhere and with better reliability than this task offered.

Task Recommendations: As a result of this analysis, it is recommended that this task be dropped. This presents no hardware or telemetry savings. It reduces the experiment procedures and performance time-line by a slight amount.

7.2.6 SUSTAINED AND IMPULSE TORQUE TASK

The results of the Sustained and Impulse Torque emissions are summarized in Table 7-6. The comparative findings essentially confirm the results of the Sustained and Impulse Force Task. Data collected in both these tasks is valuable, however, first because it increases confidence in conclusions about the major experimental conditions, and second because both torque and force data are inherently valuable to spacecraft designers and mission planners. Because of this value, torque emission data is presented in Figure 7-2.

The significance of the results for this task is discussed below:

MODES - Performance differences across simulation modes were statistically significant at the .01 level for sustained torques and the .005 level for impulse torques. As in the force task, 6 DOF performance was consistently much lower than performance in the other 0-g simulation modes, lending further credence to the hypothesis that subjects tend to allow their performance to be affected by the potential dangers involved in 6 DOF simulation. It should also be noted that impulsive torquing capability is approximately 50% greater than sustained torquing capability. This finding is all the more interesting since previous studies and results have demonstrated almost a 2.5 to 1 ratio in favor of impulsive vs. sustained <u>forces</u>. Suggested here is the result that an astronaut can more closely sustain his maximum torquing capability than he can his maximum force producing capability. An additional finding is that sustained and impulsive torquing capability are relatively insensitive to different simulation modes (less than 15% variation from 1-g to the simulated 0-g modes when the 6 DOF simulation is ignored).

SUITS - As with force emission capability, different suit conditions did not differentially affect torque emission capability. However, the 50% improvement in impulsive torquing ability over sustained torquing ability continued to be evident.

RESTRAINTS - The results of restraint conditions also duplicated force task results. Performance differences were significant at the .005 level for sustained torques but not significant for impulsive torque . The ineffectiveness of the waist restraint for sustained torque emission is again exemplified as well as the impulsive vs. sustained relationship noted above.

. INSTRUCTIONS FOR USE OF FIGURE 7-2

The next six pages contain summary data of the sustained and impulse torque task. The data are presented for the one-g and for a simulated 0-g case which consists of the average of data from the KC-135, 6 DOF and Neutral Buoyancy simulations. It was deemed necessary to present average data for these three simulations since no single case is necessarily representative of the true 0-g situation.

The data are presented using a vertical bar-graph format, which is interpreted as follows:

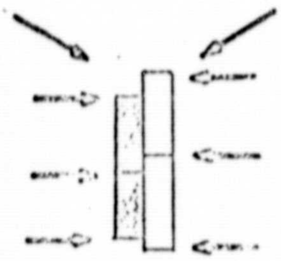
FORCE RECEIVER POSITION

Center — Lower Left

Maximum force recorded — Maximum force recorded

Average force recorded — Average force recorded

Minimum force recorded — Minimum force recorded



"Center" refers to a position where the force receiver handle is located directly in front of the subject's right nipple; "lower left" locates the handle about 12" below and 15" to the left of the center position. All other experimental conditions are clearly labeled on the chart.

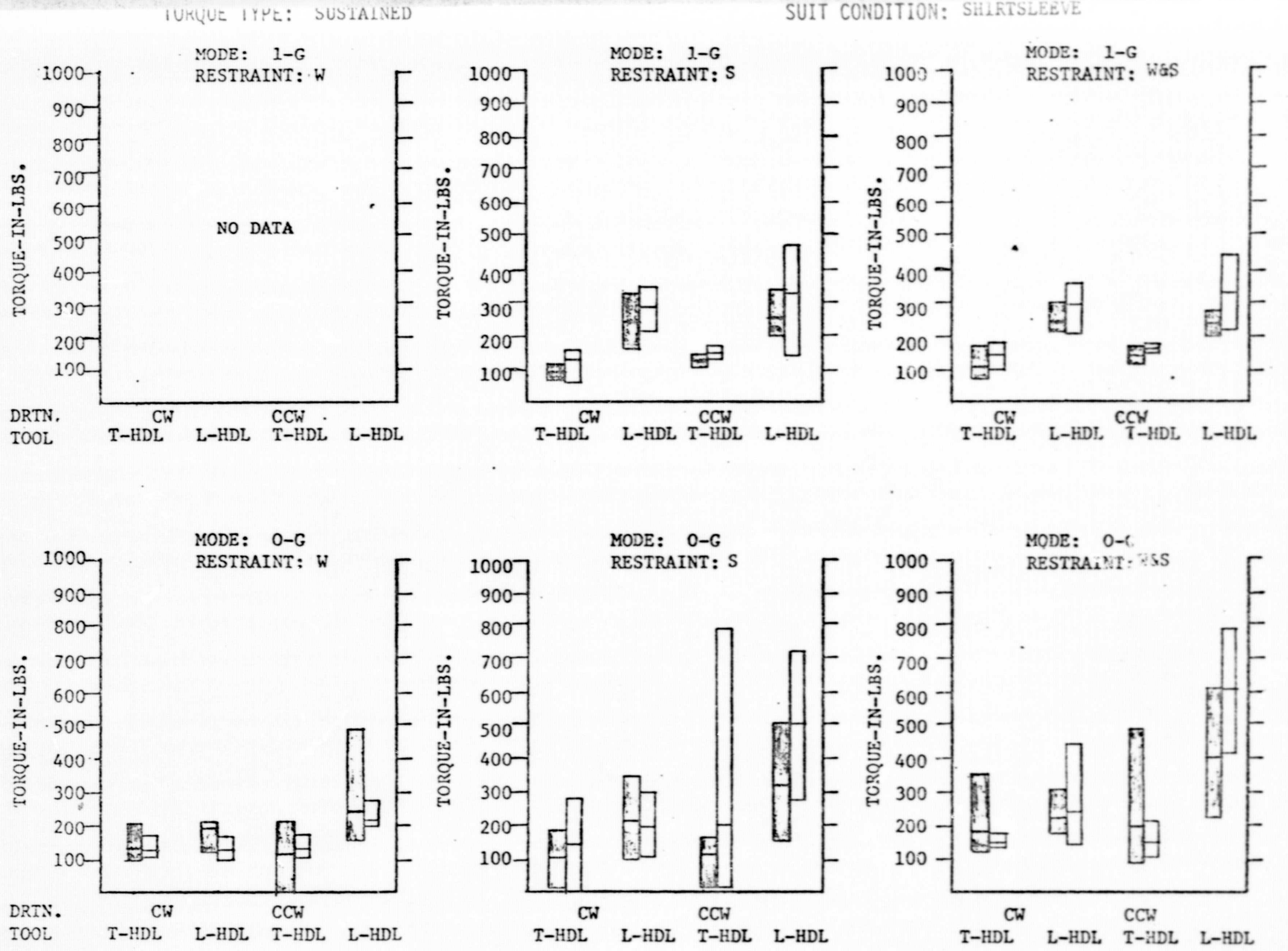


FIGURE 7-2 SUMMARY DATA CHART NO. 1

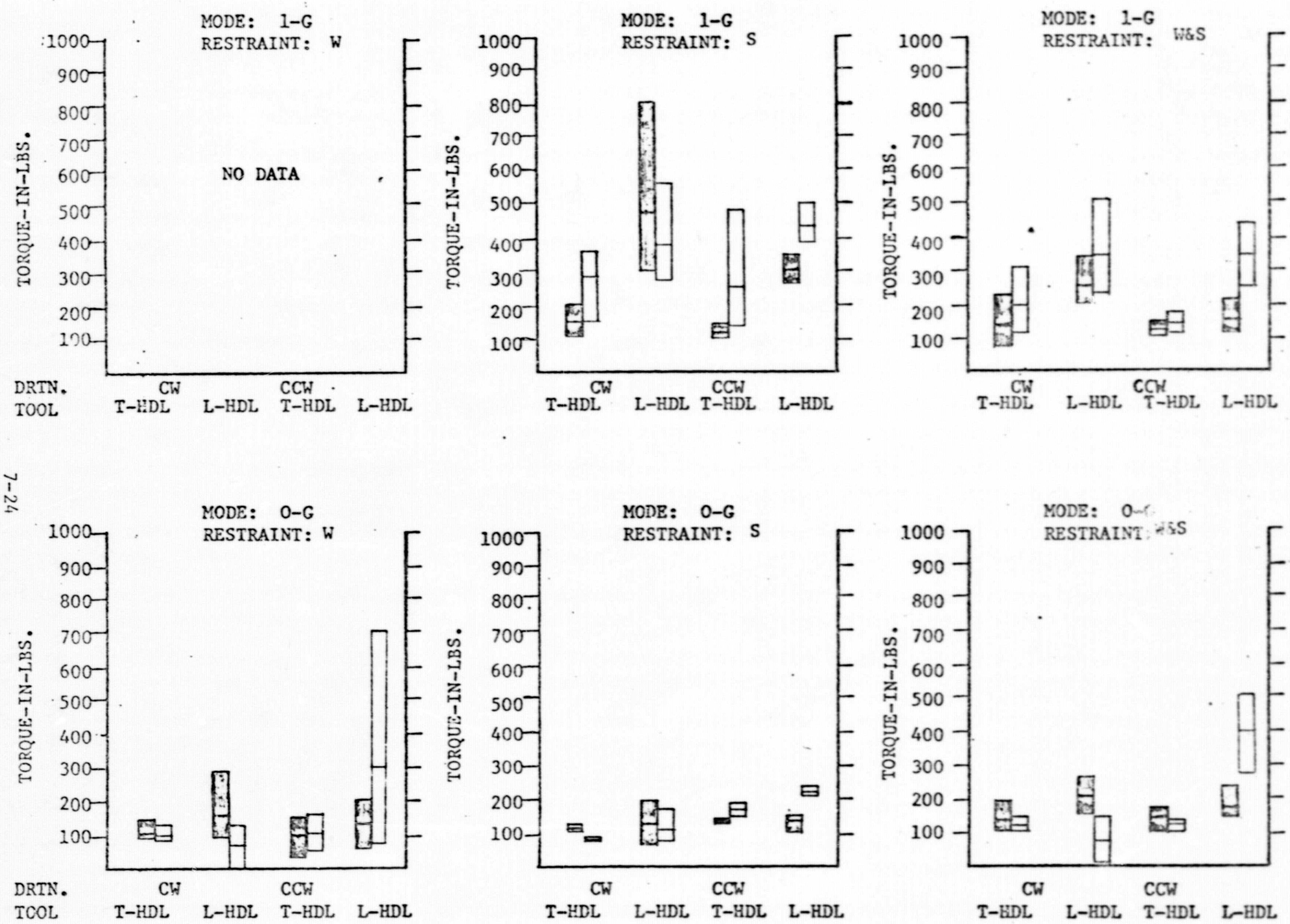


FIGURE 7-2 SUMMARY DATA CHART NO. 2

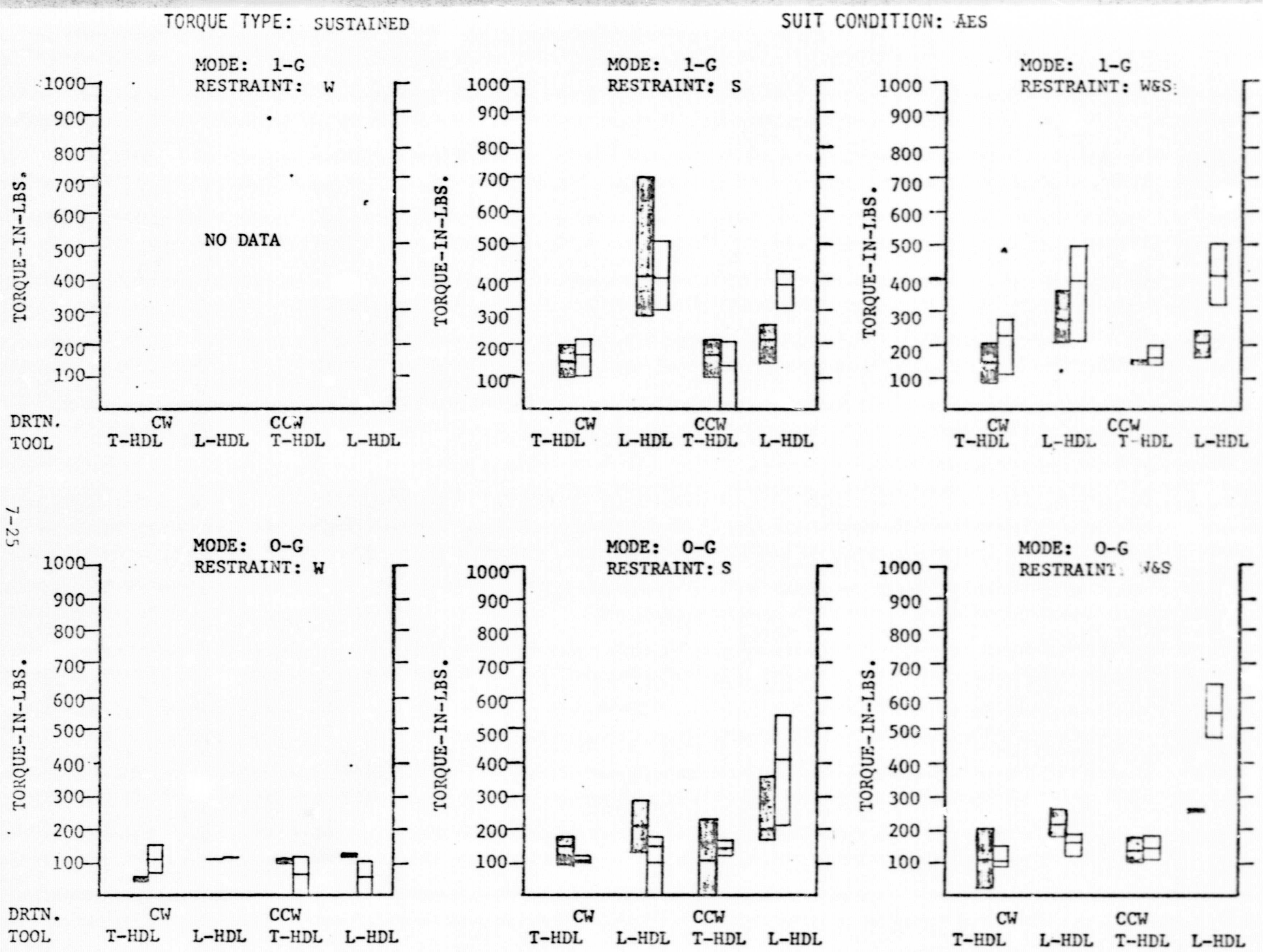


FIGURE 7-2 SUMMARY DATA CHART NO. 3

TORQUE TYPE: IMPULSE

SUIT CONDITION: A/L

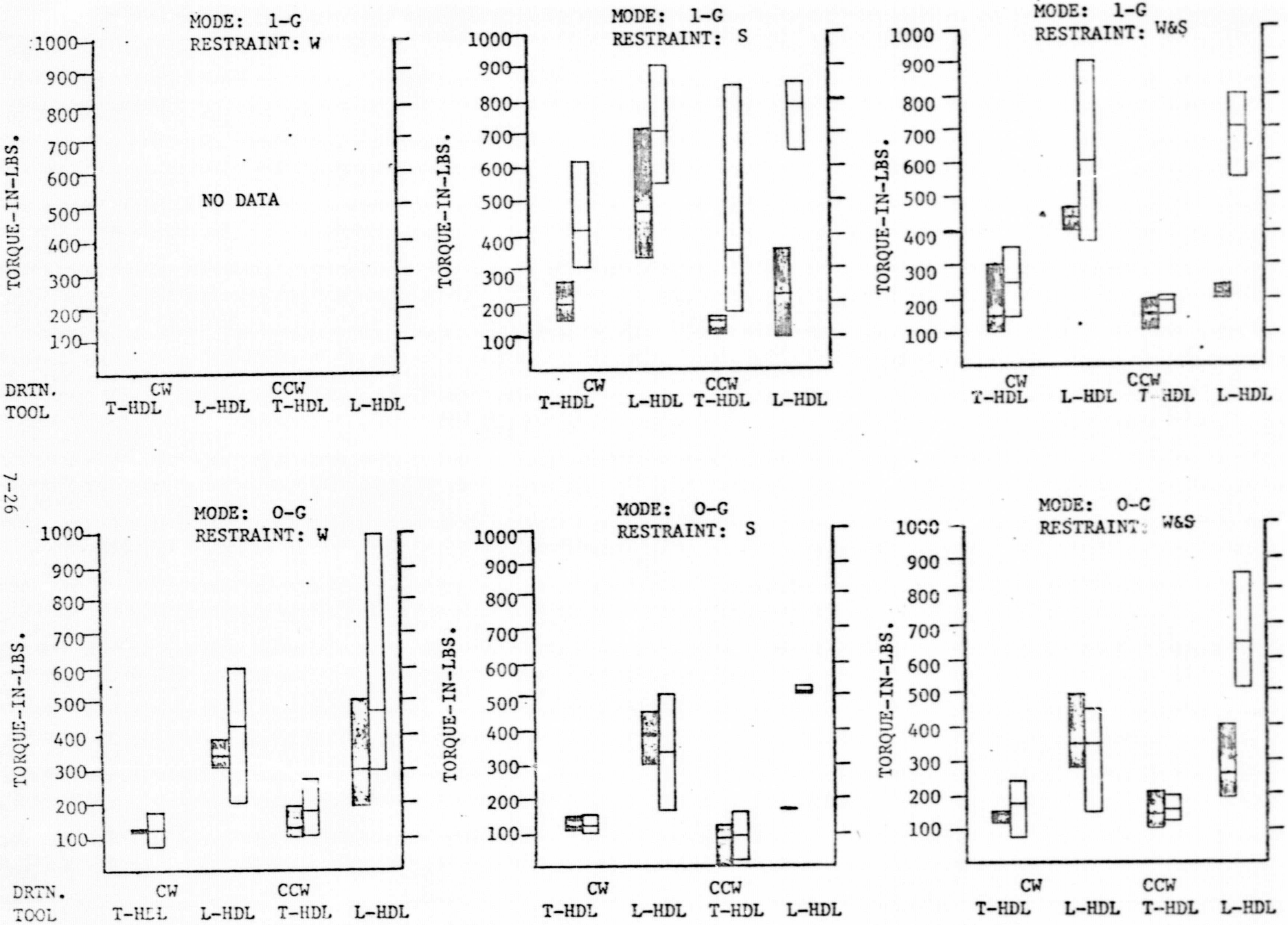


FIGURE 7-2 SUMMARY DATA CHART NO. 5

TORQUE TYPE: IMPULSE

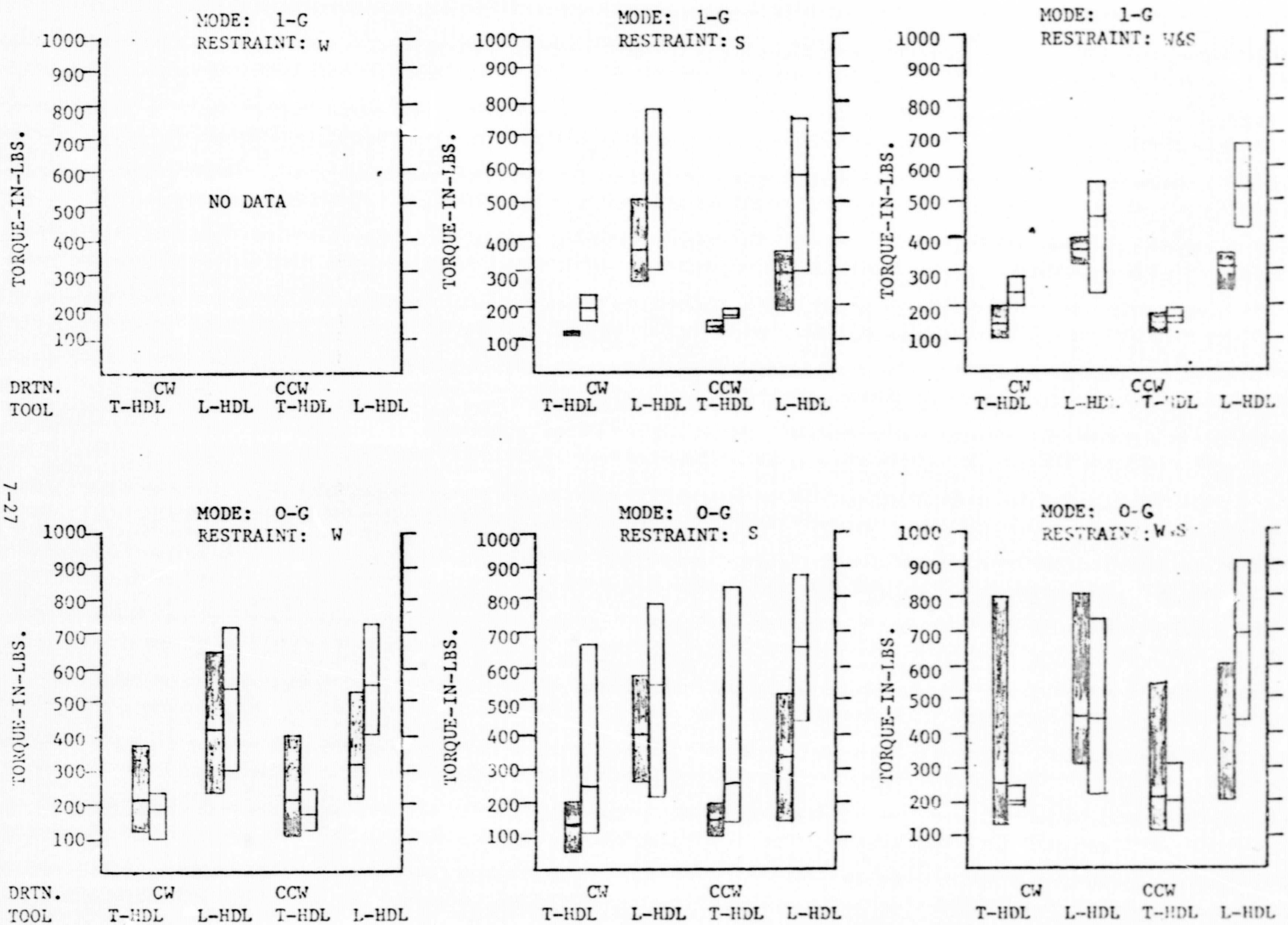


FIGURE 7-2 SUMMARY DATA CHART NO. 4

TORQUE TYPE: IMPULSE SUIT CONDITION: W&S

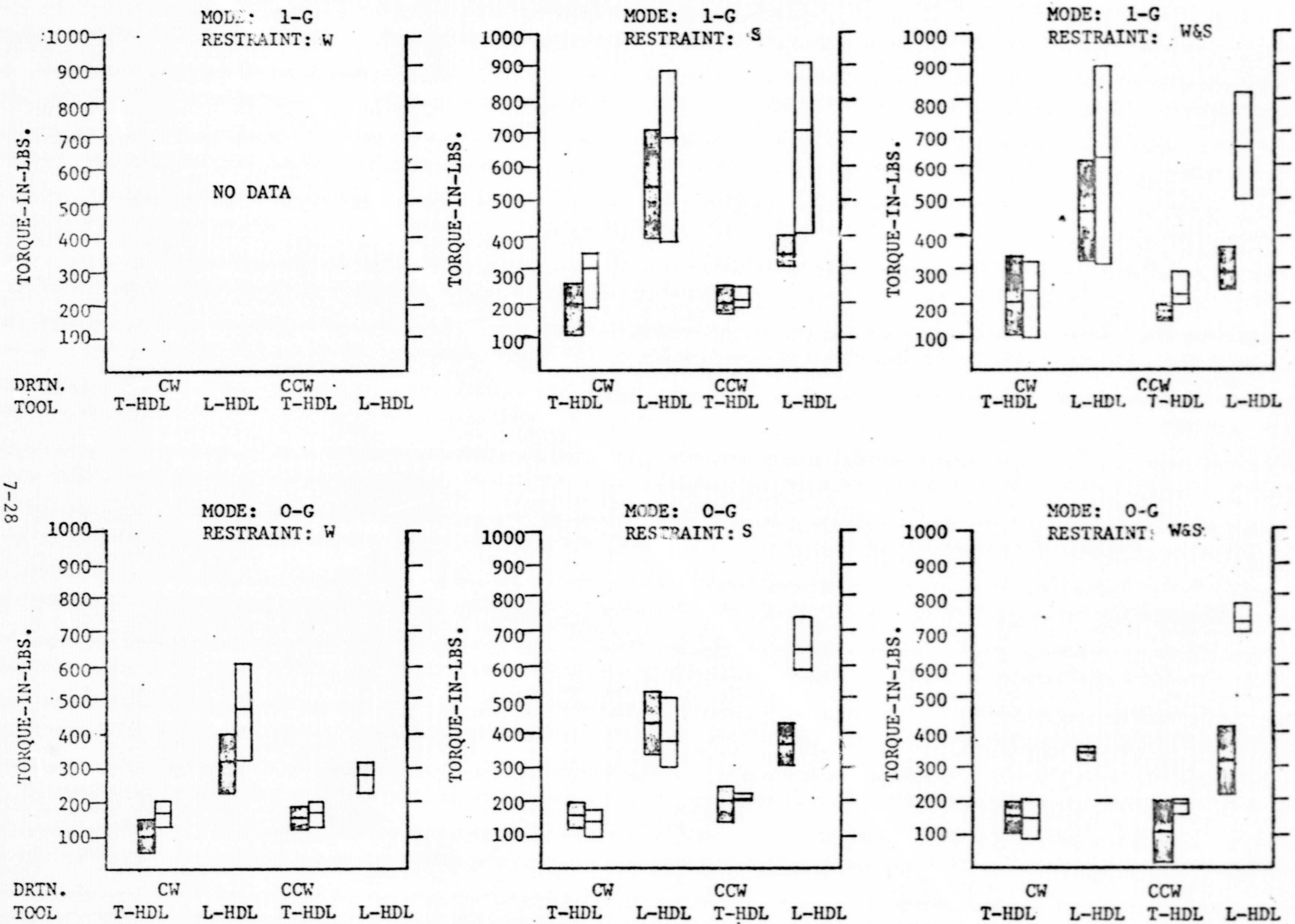


FIGURE 7-2 SUMMARY DATA CHART NO. 6

TABLE 7-6

RESULTS SUMMARY - SUSTAINED, IMPULSE TORQUE TASK

VARIABLE		SUSTAINED (FIN)	IMPULSE (MAX)
MODES	1-G	241.7 In-Lb.	352.5 In-Lb.
	NBS	212.5	369.3
	6 DOF	163.0	242.0
	KC-135	223.5	352.0
SUITS	SS	218.3	334.7
	A7L	208.7	319.1
	AES	220.3	344.6
RESTRAINTS	W	140.9	298.7
	S	231.4	347.0
	W&S	228.7	329.8
POSITIONS	Center	193.7	266.9
	Lower Left	238.3	398.9
TOOLS	L-Handle	283.9	470.9
	T-Handle	148.2	194.8

7.2.6 SUSTAINED AND IMPULSE TORQUE TASK (Continued)

POSITIONS - The lower left position permitted much greater torque emission than the center position. This reflects that in the center position, only arm muscles can be used for torquing; with the receiver in the lower left position, all the back and shoulder muscles are brought into use.

TOOLS - The direction of the difference in torque emission capability as a function of tools is as expected. The task, however, provides objective quantification of the magnitude of this difference.

In summary, this task provided confirmation of the results of the force emission task. In addition, it provides useful design data relevent to the magnitude of the torques that can be generated and sustained under specific combinations of conditions.

Task Recommendations: No major recommendations are made for this task. The measures "MIN" and "MAX TIME" may be deleted, but this represents no changes for the telemetry list.

7.2.7 TIME DATA RESULTS

Several elements of the experimental sequence were evaluated only by the time required to perform them. The main significance of such results was related to suit and simulation conditions.

Removal of the Task Panel cover (gain access task) took twice as long in the AES suit and three times as long in the A7L suit as did the shirtsleeve condition. Similarly, force receiver module removal/replacment took twice as long in the AES suit and 2.2 times as long in the A7L as did the shirtsleeve condition. The removal/replacment of the Precise Hand Movement module revealed no significant conclusions across any experimental variables.

No significant conclusions could be drawn from the restraint installation and removal tasks. Basically, this type of task is too dependent upon the specific nature of the equipment being used to permit extrapolation of any general conclusions.

The time results of the Operational Maintenance Task indicated a two-to-one ration between performance in a suited condition vs. a shirtsleeve condition. No differences, however, were noted between the two different suits. The only other important result from this task confirmed the existence of a simulation effect upon performance, with the KC simulation resulting in the fastest task time.

7.2.8 QUESTIONNAIRE DATA RESULTS

The questionnaires, described in Section 5, were analyzed to discover any additional important results on conclusions. No statistically significant response differences were noted across simulation modes or across restraint

7.2.8 QUESTIONNAIRE DATA RESULTS (Continued)

conditions. However, a strong preference for the AES suit over the A7L suit (significant at the .01 level) was noted in the 1-g simulation. It cannot be inferred, of course, that this preference will carry over into the zero-g condition.

7.2.9 SUMMARY RESULTS

All of the tasks evaluated above were found to meaningfully differentiate between simulation modes. Generally, the KC-135 simulation caused subjects to hurry through their tasks. It was also found that 6 DOF simulation caused subjects to be conservative in their force and torque emissions. Without flight validation data, however, it is impossible to conclude which simulation mode (if any) best represents the true zero-g condition. The important conclusion here is that there is an effect upon performance due to the nature of the simulation technique and this experiment is capable of detecting that effect.

Suit differences were noted mainly from the Two-Hand Task and the Precise Hand Movement Task. Although some of these results were clearly important, it is apparent that a total suit evaluation objective cannot really be satisfied only by performing worksite-limited tasks. It is recommended that some non-worksite tasks be devised to improve this capability.

The force and torque emission tasks provided reliable and important conclusions regarding the restraint systems used. It is important to note that the waist restraint performed quite poorly, but the model used was a prototype and not the electrically operated unit originally intended for this experiment. Also, the Dutch Shoes should be redesigned to better accommodate the AES suit.

The Two-Hand Task indicated that, of the restraints evaluated, no important performance differences arose. Negative conclusions such as these are of value, since this indicates that the nature of the restraint is not a prime consideration for performance of a relatively static two-hand coordination task. Again, the important conclusion is that the tasks are capable of evaluating the effectiveness of alternative restraint systems.

In conclusion, the implementation of the recommendations contained throughout Section 7 will definitely result in an efficient and effective Experiment M508 which will indeed evaluate the selected pieces of EVA hardware (especially suits and restraints), satisfy the objectives of the Simulation Technique Evaluation Program, and provide useful design data on EVA/IVA performance capabilities in the zero-gravity environment.

SECTION 8

HANDBOOK OF HUMAN ENGINEERING DESIGN DATA FOR REDUCED GRAVITY CONDITIONS

The handbook contained in Volume III of this report was prepared as "level of effort" development in conjunction with the experimental design and implementation phases of this study program. The primary purpose was to develop a handbook of human engineering data for the use of engineers, designers, and human factors specialists during the developmental and detail design phases of manned spacecraft programs.

8.1 HANDBOOK DEVELOPMENT

In the process of defining the probable usage of this text, it was determined that the basic handbook would not only be used as an authoritative reference source for individual designers in respect to establishing specifications and requirements for physical man/machine interfaces, but could also provide the basis for standardization of operational protocol development. The publication and common use of authoritative absolute descriptors of the various needs, capabilities and tolerances of crewmen might also provide the basis for the establishment of standarized levels of capabilities for describing crew selection and training criteria in respect to the designation of specific maintainability tasks to individual crewmen. With this in mind, it was decided to follow the precedents set by such documents as the Handbook of Chemistry and Physics, Biology Data Book, etc., i.e., the selected format for the document should consist of a repository of detailed, quantified data in tabular or graphic form whenever possible. The final document must provide readily accessible detailed data describing all pertinent functional or survival-critical interactions between man, his working environment, his vehicle and support hardwares.

While, as previously stated, it is hoped that widespread utilization of the text material will permit standardization of design practice in respect to vehicle, equipment, and operations, the document must also be capable of providing custom-tailored specifications for unique mission/equipment/environment interactions.

8.2 DATA COLLECTION

Literature searches were requested from the National Aeronautics and Space Administration's Scientific and Technical Information Division as well as the Defense Documentation Center (DDC) regarding human performance in a reduced gravity environment. These searches were reviewed, and those items that appeared to contain required human performance data were ordered for review. The services of the Tufts University Human Engineering Information and Analysis Service (HEIAS) were also utilized during this effort. Volumes I and II of the HEIAS bibliographies were searched for space-related categories most relevant to the task. As a result of this search, a printout of approximately 500 references was developed. Items to be entered into the upcoming Volume III of the HEIAS Bibliography were also reviewed for relevancy. The NASA and DDC searches were arranged in ascending "AD" "STAR" accession numbers, respectively, when they were received. The basic HEIAS system carries the titles and abstracts of documents by accession number but cross-indexes the accession numbers of the documents by an alphabetical listing of primary categories relevant to human factors interests. In order to

8.2 DATA COLLECTION (CONT'D)

eliminate title duplication and facilitate the location of titles and abstracts, the HELAS system was utilized as the basic collation system.

A basic review of currently available documentation was initiated, and basic data regarding human operator performance was collected. In this effort, the goal was to gather primarily empirical or experimental data generated in an actual or simulated reduced gravity environment.

8.3 DATA APPLICATION

It was felt that a document of this type should permit deliberate and detailed data to be available for four basic tasks that are currently deemed necessary when designing for maintainability in a manned orbiting system. For optimum maintainability potential, the following discrete tasks must be accomplished:

Task A. The vehicle and all its subsystem housekeeping, structural, and mission-related hardwares must be deliberately analyzed in respect to the possibility of needing in-orbit maintenance. In those instances where maintenance during orbital operations is deemed both possible and feasible, specific efforts must be expended in order to ensure ease of diagnostics, access, institution of corrective procedures, and checkout capabilities. These hardware designs shall also consider packaging and general corrective processes involved in respect to minimizing "unique" technological skills, special tooling, instrumentation, facilities, and man-hours necessary to effect the repairs while maximizing the safety and efficiency of access to the work site.

Task B. The designer shall detail all crew support facilities and equipments necessary to accomplish the transport, restraint/tethering of the crewman and his materials at the work sites, as well as to provide an environment that is conducive to both work and survival.

Task C. The responsible system designers shall develop specifications necessary to describe the physical and functional characteristics of the maintenance interface including sizing, configuration, and information flows across the man/machine interfaces at the various potential work stations.

Task D. The designers must, as part of their maintainability tradeoffs, consider the capabilities of man in light of the constraints imposed by the system and the environment in the design and assignment of maintenance roles to the "orbital man".

To reiterate, the large preponderance of material selected for this document is expressed in graphic and/or tabular form with prose commentary limited

8.3 DATA APPLICATION (CONT'D)

to explanations of techniques utilized in the application of specific data. Prose is also utilized in "term definition" as indicated.

8.4 HANDBOOK ORGANIZATION

In selecting the basic generic headings for Human Engineering Handbook, heavy emphasis was placed on potential usage. Section 1 contains that information related to the description of human characteristics. Provisions are made for information which will permit allowances for man's physical and functional dimensional requirements as well as descriptors of his general motor, sensory, and cognitive performance capability. Information regarding his tolerance to various forms of physical, emotional, and environmental stressors are also provided in this section.

Section 2 has provisions for absolute value data which describes the composition and the various phenomena present in the orbital intravehicular and extravehicular environment. Data in this area involves discussions concerning the design requirements for the intravehicular environment related to atmospheric control, illumination levels, rotational dynamics and habitability. Extravehicular environmental considerations involve data on space hazards, effects of weightlessness, radiation levels, temperature extremes and illumination factors.

Section 3 has provisions for data which will describe the minimal and/or optimal physical and functional characteristics of hardware design where it might interface with man and modify his performance. Data in this area includes sizing, configurational, operational, and dynamic considerations for the vehicle and all its facilities including unique mission equipments, packaging and access.

8.5 RESULTS AND RECOMMENDATIONS

The results of the effort to develop a Handbook of Human Engineering Design Data for Reduced Gravity Conditions are presented in Volume III of this report under the above title. This unique document provides detailed quantified data on man's capabilities and tolerances for survival and productive effort in the extraterrestrial environment. It also provides quantified data on the space environment man will work and live in as well as the characteristics of the vehicular environment he will need. A detailed, topical Table of Contents has been developed to provide easy and efficient access to the data to encourage the utilization of the document among technical specialists involved in the design and construction of manned spacecraft.

Due to modifications to costs and funding levels, it was decided late in the program to sacrifice the development of an index and glossary rather than modify the depth and breadth of the data presented. At this time, it was also decided to increase the detailed structure and completeness of the Table of Contents to minimize the effect of the absence of an index.

8.5 RESULTS AND RECOMMENDATIONS (CONT'D)

Further savings in data collection and presentation were made by minimizing publication costs via the use of direct reproduction of graphic and tabular material rather than redrafting for common format, and the common listing of references rather than the original contiguous foot note referencing originally contemplated.

Because of the above noted modifications and the significant amount of new and updated information published annually, it is recommended that a yearly addendum be published and distributed to document holders, and a revised edition be considered every two (2) years.

SECTION 9

EXPERIMENT 84 A' & B

9.1 INTRODUCTION

This experiment was performed to provide one-g and zero-g shirtsleeve baselines for the force emission data collected during Experiment 84A which was performed at the Marshall Space Flight Center Neutral Buoyancy Facility in Huntsville, Alabama, under Contract NAS8-18117. In that experiment, "Force Application in Simulated Zero Gravity", the effects of restraint, force receiver angle, force receiver distance, and handle orientation on force emission capability in the pressure suited condition were evaluated. In order to increase the validity of extrapolation from 84A, two sampling experiments were performed during this contract in a format allowing statistical comparison with 84A. These experiments were called experiments 84A' and 84B. The experimental design of 84A was used as the baseline for the design of the follow-on studies.

The two experiments in the current program were intended to provide the answer to two additional questions:

a. What is the effect on man's 1-g baseline force emission capability as a result of the zero gravity environment?

b. What is the effect on man's shirtsleeve baseline force emission capability as a result of a pressurized space suit.

9.2 OBJECTIVES

Measurement of the maximum impulsive and sustained force generation capability of man as a function of the systematic variation of restraint conditions will provide the spacecraft designer with comparative data on the relative values of specific types of restraint systems. By varying the orientation and location of the force receiver, it is also possible to provide comparative data to evaluate the relative effects of accessibility and variations of the work envelope on man's force application capabilities. While the restraint conditions selected for testing are not all applicable to present day spacecraft, these experiments were designed to generate sufficient information to assist the designer in specifying and designing new and better restraint systems than those presently available. The design of an optimum restraint when a desired force emission capability is required will be possible on a quantitative basis if the appropriate data are available. Also, since the astronaut will be provided with a restraint system which controls and/or limits his movements, the availability of force emission capability data as a function of force receiver location and orientation will assist the designer in the solution of the man/machine interface problems. Therefore, the major objectives of these experiments are to:

a. Broaden the force emission capability baseline data to permit extrapolation from the shirtsleeve to the pressurized space suit environment.

b. Broaden the force emission capability baseline data to permit extrapolation from the 1-g to the 0-g environment.

9.2.1 EXPERIMENT 84A' NON-PRESSURE SUITED EXPERIMENT

The first of the new experiments, 84A', used the non-pressure suited or shirtsleeve zero gravity environment to provide a baseline with which to evaluate the force emission capability loss due to pressure suit restrictions. Also, since intravehicular activity (IVA) may be assumed to be more common than extravehicular activity (EVA), and since more difficult activities may be scheduled IVA because of the less restricting and less hostile environment, quantified data concerning force emission capability in the shirtsleeve zero gravity environment may be of greater use and application than the data collected already for EVA. The design of the shirtsleeve experiment was greatly simplified compared to the 84A experiment because the results from 84A have been used to delete variables or levels of variables which were found to be non-significant with respect to astronaut force producing capability. The conduct of the experiment and the data reduction are simplified by the use of techniques, computer programs, and scheduling criterion available from 84A.

9.2.2 EXPERIMENT 84B ONE-G BASELINE EXPERIMENT

The second of the experiments, 84B, was designed to study the effect of gravity on force producing capability. Performance of the same conditions used in 84A, where possible, in a 1-g environment will allow a quantified comparison which may result in a conversion factor or series of conversion factors for gathering zero gravity data in a one-gravity environment. A simplified version of the 84A protocol was used, dropping the variables found non-significant in 84A and also the variables which could not be simulated in 1-g (ex: no restraint).

9.3 EXPERIMENT DESCRIPTION

9.3.1 GENERAL DESCRIPTION

This experiment was concerned with determining the effects of zero-gravity on the force-producing capabilities of subjects as a function of the type of restraint and simulated conditions of accessibility. In this study, the restraints were varied in the number and location of the energy sinks provided to the subject. Additionally, the accessibility conditions were evaluated by changing the location and orientation of the force receiver with respect to the subject.

The subjects performed the tasks in one of two suit modes: Gemini G4C suit, pressurized to 3.5 psi or shirtsleeve. Zero gravity was simulated by the technique of neutral buoyancy submergence.

The experimental apparatus was designed to provide efficient selection of the experimental condition combinations by an underwater technician. The experimental condition combinations consisted of eight types of restraint (including no restraint), two force receiver distances, and two force receiver angles.

9.3.1 GENERAL DESCRIPTION (Continued)

Maximum impulse and sustained forces were obtained from each of two subjects for each experimental condition. Impulsive forces were defined as the peak forces exerted during a 1.0 second internal, while sustained forces are defined as the minimum force maintained over a 4-second interval. The required forces were applied in push, pull, left, right, up, and down directions, at all force receiver locations.

Prior to each experimental run, the subject was attached to one of the restraint systems and stabilized in front of the force receiver handle. The handle had been previously set at one of the experimental distances and angles. When all personnel were ready, the test director initiated signals which displayed on the subject's cue panel the required direction and type of force to be exerted. After a 2-second cue time, a "go" signal was displayed to the subject, who was instructed to exert the appropriate force until the "go" signal extinguished. After a suitable rest period, new cue signals were displayed to the subject, and the above procedure repeated. After performing 12 trials of required force exertions (sustained and impulse forces in all six directions), the handle orientation and/or distance was changed, and a new sequence of 12 trials begun. An experimental session consisted of 96 trials, and the experiment required 12 sessions to complete the data collection across all experimental conditions.

9.3.2 EXPERIMENT VARIABLES

The ability of an astronaut to exert forces in a zero-g environment is influenced by several factors, some of which are:

a. Type of restraint system

b. Location and number of restraint attachment points

c. Position and location of the body relative to the force receiver

d. Manual or tool assisted force requirements

e. Type of force required - impulse or sustained

f. Direction of force application

g. Location and orientation of force receiver

h. Type of spacesuit

i. Physical size of subjects

j. Suit pressurization method

9.3.2 EXPERIMENT VARIABLES (Continued)

However, evaluating the effects of all parameters of these variables was beyond the scope of this experiment. The variables selected for investigation in this experiment were:

a. Type of restraint system

b. Receiver angle

c. Receiver distance

d. Force direction

e. Force type

f. Subject

g. Suit condition

The ranges of the variables used in this experiment were selected with the intention of establishing the parameters of the principal factors affecting force-emission capability in zero-gravity. The same experimental conditions were used in these experiments as were used in 84A with certain exceptions as described below.

9.3.3 TYPE OF RESTRAINT SYSTEM

Restraint is perhaps the most important variable affecting force-emission capability in zero-gravity. The effectiveness of any given restraint is due to its efficiency as an energy sink and stablizer in resisting the effects of the force emitted by the subject in any given direction. The restraints selected for this experiment were those which appear to be most representative of the current thinking on probable types and combinations, and include:

	Use in 1-G
a. None (no restraint)	No
b. Handhold only	No
c. Waist only (2 point, rigid)	No
d. Gemini Dutch shoes only	Yes
e. Handhold and waist	No
f. Handhold and shoes	Yes
g. Waist and shoes	Yes
h. Handhold, waist, and shoes	Yes

9.3.3 TYPE OF RESTRAINT SYSTEM (Continued)

Note that in the 1-g condition only those combinations of restraints involving the shoes were utilized.

9.3.4 RECEIVER ANGLE

The location of the force receiver in the subject's reach envelope is a major determinant of force emission capability. However, the extremely high number of possible locations prohibits an all-inclusive study of the effects of location. One aspect of location selected for investigation was the horizontal angle subtended by the location of the force receiver with respect to a fixed point on the subject's frontal plane, assuming the subject to be oriented vertically. The origin in this case uses the reference point of the right shoulder, with the arm held straight out being zero degrees. All of the angles used were in the plane which was perpendicular to the sagittal axis and intersect the subject's right nipple. The statistical analysis of the 84A data indicated that there was no significant difference between the 0° and the -15° receiver angles. It was decided to use only the -15° and the 45° receiver angles in this experiment. The -15° was chosen over 0° because the -15° to 45° allows a test over a greater experimental range, encompasses the 0° point, and therefore, permits greater generalization of the data.

9.3.5 RECEIVER DISTANCE

Another aspect of accessibility investigated in this experiment was the distance from the subject to the force receiver. The intent to bracket the range of possible distances can be seen in the theoretical definitions of the three receiver distances chosen for inclusion in the original 84A experiment. The distances, called near, medium, and far, were determined to sample the reach envelope.

In the statistical analysis, receiver distance was not found to be significant, but "near" and "far" had individual advantages in certain force directions. "Near" was determined to be 15 inches forward of the shoulder reference point and, was defined as the closest position that could practically be reached while wearing a pressurized space suit. "Far" was determined to be 24 inches forward of the shoulder reference point, and was defined as the farthest position that could practically be reached. The actual distance in inches varies slightly between subjects and was restricted slightly by equipment limitations.

9.3.6 HANDLE ORIENTATION

Statistical analysis of the 84A data also showed no significant difference between vertical and horizontal handle orientations, however, the vertical orientation appeared to be slightly better. For this reason the horizontal orientation was dropped, and only the vertical handle orientation was used in this experiment.

9.3.7 FORCE DIRECTION

Since force-producing capability varies greatly with the intended direction of force application, subjects in this experiment were asked to generate forces in both directions of the three orthogonal axes defining the location of the force receiver. The directions of force application were:

a. Push

b. Pull

c. Left

d. Right

e. Up

f. Down

9.3.8 FORCE TYPE

Two types of data concerning force-emission capability especially useful to the designer of advanced space systems are impulse and sustained forces. The former is defined as the peak force that is exerted during a 1-second interval, and the latter defined as the maximum force capable of being maintained during a 4-second interval. Quantitative data for these two types of emission will allow the equipment designer to answer the questions:

a. What is the peak force which the astronaut can be depended on to produce in a given condition combination?

b. What force can the astronaut maintain for a reasonable amount of time?

In this experiment, the subject was instructed to exert maximum force in the direction indicated on the cue panel, and to hold this force until the "go" signal extinguished. The cue panel communicated the force type by presenting either the word "impulse" or "sustained" at the same time the instruction for force direction was presented. After the 2-second illuminated cue period, the "go" signal appeared and was maintained one second for impulse trials and 4 seconds for sustained trials. The instruction or cue signal also remained on until the termination of the "go" signal.

9.3.9 SUBJECT DIFFERENCES

One of the primary questions requiring an answer early in the analysis of the data is concerned with the "sameness" or difference between the subjects used in the original 84A and the current 84A' and 84B experiments. If the subjects used in the two experiments differ significantly with respect to their force emission capability, then the ability to extrapolate from the 84A data will be questionable at best.

9.3.10 SUIT CONDITION

Two parameters of the suit condition variable were evaluated in this experiment. The shirtsleeve mode (not wearing a pressure suit) was used in both the 1-g and 0-g simulation. The pressurized suit (Gemini G4C spacesuit) was utilized in the 1-g and 0-g simulation. The Gemini G4C suit was selected as being most comparable to the Apollo State-of-the-Art suits used in the original experiment and available for use in the current program. The suit was water pressurized to 3.5 psia by a system developed by GE and described in detail in the study report on Contract NAS8-18117.

9.4 EXPERIMENT SET-UP

The 84A' and 84B experiments were performed at General Electric's Controlled Buoyancy Facility at Valley Forge, Penna. The hardware is described in detail in the study report on Contract NAS8-18117 and need not be repeated here.

9.5 DATA ANALYSIS AND RESULTS

9.5.1 DATA REDUCTION

All data collected from this experiment were manually transformed to coded sheets. The coding system identified each data point according to the variables in effect when it was collected. The computations performed with this data were similar to those performed on the M508 data. A time-shared computer program permits various combinations of data to be averaged and printed out in a format compatible with the 84A data formats for comparison.

The measures computed are similar to those computed for the 84A experiment and are as follows:

MIN - The minimum force that occurs in the commanded direction during the last 3 seconds of the 4-second command for sustained forces.

MAX - The maximum impulsive force that occurs during the 1-second the GO-light is on and the 1 second afterwards.

The mean, range and number of points found for these measures were computed and displayed for subsequent data analysis.

9.5.2 RESULTS

When compared with the 84A data a rather unfortunate result was noted. A difference in magnitude of approximately 2:1 exists for each of the paired directions of a given axis. The effect is most obvious in the range of MAX forces. The largest force in the PULL direction is 175.0 lb; in the PUSH direction it is only 78.0 lb. The other two axes exhibit similar behavior.

9.5.2 RESULTS (Continued)

This effect was not at all noticeable in the 84A data and there is no plausible reason to suspect such an effect here. A study was made of the distribution of data collected here and ultimately it was decided that, for the PUSH, LEFT and DOWN directions (all of which were characterized by negative voltage outputs), the recorder was being operated near saturation in the 50-70 lb. region. Thus the problem could not be spotted during experiment operations. The daily calibration procedure utilized a fish scale to exert known forces. Using this technique only forces up to about 50 or 60 pounds could be reliably maintained. Thus, it went completely unnoticed that forces of perhaps 100 or 120 lbs. were being damped at 60 or 70 lbs. The magnitude of linear deviation on the recorder was such that this damping would not readily be noticeable. As a result of this problem, it was deemed necessary to eliminate the LEFT, PUSH and DOWN direction from consideration and utiiize only the RIGHT, PULL and UP directions for comparison with 84A.

The following paragraphs describe the results of the data analysis and comparisons conducted to evaluate the capability of extrapolating from the original Experiment 84A 0-g pressure suited data to the 1-g and 0-g shirtsleeve conditions. The statistical analysis performed on the data was the same as described in detail in the Contract NAS8-18117 Final Report. The two non-parametric statistics used were the Wilcoxon Matched-Pairs, Signed Ranks Test and the Friedman Two-Way Analysis of Variance.

9.5.2.1 Mean Forces Across Subjects

The first comparison evaluated the subjects utilized in the current experimental program against those utilized in the original Experiment 84A. The comparisons involved the mean of the MINS and the mean of the MAXS for the neutral buoyancy simulation case in the new data (84A') and the old (84A) data. The results indicated there were no significant differences between the current subjects and the original subjects in terms of their ability to exert sustained or impulsive forces.

9.5.2.2 1-G Versus 0-G Force Emission Means

The next analysis compared the mean force emission capability in a 1-g environment with the mean force emission capability in the neutral buoyancy simulated zero-g environment. Results of this analysis indicated that sustained force emission capability differed significantly at the .05 level across the 0-g and 1-g environments. The same result (a significant difference at the .05 level) was found when comparing the mean impulsive force emission capability across the 2 gravity conditions. In spite of the statistical significance of the difference in impulsive force emission capability, it appears that the magnitude of the real difference is not very important. The zero-g means differed from the 1-g means by only 2 to 12 lbs. representing a 3 to 20 percent variation. In all cases, the 1-g mean fell within the range of the zero-g means. The 20% difference in the means was found in the Up direction only and indicated a difference that is later confirmed by the suited vs. shirtsleeve analysis in which there appears

9.5.2.2 1-G Versus 0-G Force Emission Means (Continued)

to be a suit restriction in the capability to exert Up forces. In the case of sustained forces, there appears to be an increased force emitting capability in the 1-g mode that is 2.4 to 2.8 times as great as the zero-g force emission capability. These results indicated that impulsive force emission is relatively uneffected by changes in gravity conditions and that sustained force emission capability is approximately 2-1/2 times as great in the 1-g environment than in the zero-g.

9.5.2.3 Shirtsleeve Vs. Pressure Suited Force Emission Means

Results of the statistical analysis of the mean force emission capability between shirtsleeve and pressure suited conditions indicated no significant difference between impulsive or sustained force emission capability. However, in both the impulsive and sustained forces in the Up direction, the shirtsleeve mean force capability was approximately 40% greater than the pressure suited force emission capability. This was especially evident since all other directions indicated approximate equality in mean force producing capability between the suited and shirtsleeve modes.

9.5.2.4 Mean Forces Across Receiver Angles

Results of the statistical analysis of the mean force capability across different receiver angles indicated no significant difference in either the impulsive or sustained force cases. This finding is consistent with the results of the analysis of the original 84A Experiment and visual inspection of the data indicate relatively the same trend with respect to receiver angle and direction interactions. The capability to exert sustained and impulsive Push/Pull forces tends to increase as the force receiver is moved away from directly in front of the subject. However, this tendency appears to reverse for the other directions. That is, the Up/Down and Left/Right force emission capability tends to decrease as the force receiver is moved laterally from in front of the subject.

9.5.2.5 Mean Forces Across Receiver Distances

Results of the statistical analysis across the receiver distances indicate no significant differences for either the impulsive or sustained force emission capabilities. It appears from the data that the ability to exert pull forces is slightly enhanced as the force receiver distance is increased, and that the ability to exert up and right forces is diminished as the force receiver distance increases.

9.5.2.6 Mean Forces Across Restraints

A statistical analysis of the mean force emission capability across various restraint conditions indicated a significant difference at the .005 level for both sustained and impulsive forces. This finding is also consistent with the previous study results.

9.5.3 CONCLUSIONS

The conclusions that can be drawn from the above data analysis and results are as follows:

a. The force emission capabilities of the subjects used in the original Experiment 84A and the current Experiment 84A' and 84B did not differ significantly.

b. Impulsive force emission capability is not significantly affected by varying the gravitational field from zero to 1-g.

c. Sustained force emission capabilities in the 1-g environment appears to be approximately 2-1/2 times as great as sustained force emission capabilities in the simulated zero-g environment.

d. Sustained and impulsive force emission capabilities are relatively unaffected by the pressurized space suit except in the Up direction for the suits used in this program (Gemini G4C).

e. The data graphs summarizing the pressure suited force emission capability data collected in the original Experiment 84A are presented in Volume II of this report and can be used in the following manner:

   - The mean impulsive forces can be used to represent the 1-g and zero-g, shirtsleeve and pressure suited impulsive force emission capability.

   - The mean sustained force graphs can be used to represent the 1-g shirtsleeve and pressure suited force emission capability by multiplying the means by a factor of 2-1/2.

SECTION 10

PROGRAM CONCLUSIONS AND RECOMMENDATIONS

10.1 INTRODUCTION

This section provides a brief review and summary of the major accomplishments, conclusions and recommendations that resulted from the conduct of the Astronaut Zero Gravity Performance Evaluation Program.

10.2 CONCLUSIONS

Experiment M508 was initially conceived to provide information relative to the performance of selected pieces of EVA hardware. At a later date, it was realized that the experiment could serve as a means of evaluating the various ground-based zero-g simulations currently used for astronaut training as well as for physiological and psychomotor performance studies. Finally, it was also realized that the experiment could provide valuable zero-gravity human performance design data. The most important conclusion to be drawn from the work reported here is that all of these objectives are well satisfied by the experiment which was designed and performed for this contract.

Given that the program objectives remain as EVA hardware evaluation, simulation technique evaluation and the generation of design data, the importance of utilizing the experiment which results from execution of the individual task recommendations in Section 7 cannot be overstressed. It is worthwhile to review here the results which dictate the inclusion or deletion of certain tasks and/or experiment variables.

The Precise Hand Movement Task indicated important performance differences across simulation modes and between suited (EVA) and shirtsleeve (IVA) conditions. In addition, it was noted that the existence of a limiting access port seriously degrades one's ability to accurately perform a dynamic task. This type of information is directly relatable, for example, to the removal and replacement of small film cassettes, where precision alignment is required.

In the Two-Hand Task (a static test of accuracy) it was found that the access condition did not affect the accuracy of performance. It was also found that any relatively stable one-point restraint is suitable for such a task. This type of information would be useful in designing an astronaut function involving a task such as sensor alignment. This task also proved capable of differentiating between simulation modes and between suited and shirtsleeve conditions.

The Precise Force Task provided important results concerning simulation modes and restraints. The Precise Torque Task tended to confirm these results, but because it did not provide any conclusions or results that were new or different, this task was recommended for deletion.

The Sustained and Impulse Force and Torque Tasks also tended to confirm each other. But each of these tasks provides inherently valuable design data on a basic human performance capability and should therefore be retained. Two of the most important results found in these tasks were the existence of inhibited performance in the 6 DOF simulation and the ineffectiveness of the variable-flexibility waist tether utilized in this experiment. Design data was enhanced by being collected at various reach envelope locations, using different tools, etc.

10.2 CONCLUSIONS (Continued)

The Operational Maintenance Task, Restraint Installation Task and the Gain Access Task were all found to be too specific in nature to provide meaningful results. These tasks were recommended for deletion, resulting in a time savings to the experiment of approximately one-fourth the total experiment time.

It was stated in Section 7 that the experiment did note several important differences in performance resulting from the nature of the A7L and the AES suits. The experiment was more effective, however, for quantifying differences in an IVA (shirtsleeve) condition vs. an EVA (suited) condition. It is therefore recommended that only one suit be kept for the flight experiment. As an alternative, the "worksite only" restriction can be removed, allowing additional experimental tasks which would provide a more complete suit evaluation.

With regard to the other major experimental condition - restraints - it is recommended that the experiment utilize at least two different restraint conditions. The manually operated waist tether, however, should either be greatly improved or replaced prior to inclusion in the flight program. The Dutch Shoes must also be modified to fit the AES suit boots (if that suit is retained in the program). The important point to bear in mind, of course, is that the experiment can and will denote performance differences which result from the utilization of <u>any</u> restraints.

One of the most significant conclusions from this program has been the demonstrated value of utilizing representative tasks to provide objective, quantifiable data rather than real operational tasks that provide only subjective or qualitative data of a "Go-No Go" nature. The technique which resulted in the design of these tasks (Section 3.0) is a sound one. To some, they have seemed irrelevant and inappropriate. The technique and resultant experimental tasks are based upon consideration of the psychomotor capabilities required of astronauts to perform the experiments planned for the next decade of manned space flight. In addition, the experiment program reported here illustrates well how the representative tasks do in fact satisfy the objectives of the M508 Experiment.

10.3 RECOMMENDATIONS

The most important recommendation that can be made to NASA is that the flight validation data on this experiment be collected consistent with the experiment design as it now exists. The result of the flight experiment will literally be a human performance data bank providing evaluations and comparisons never before available. These evaluations could utilize computer programs and techniques already existing from this contract with virtually no changes. For the first time, analysts could objectively determine the most effective means for simulating zero-gravity for different tasks. It is not extreme to conceive of a situation in the future where a spacecraft designer or mission planner requires the performance of a particular task; with suitable reflection, he decides (for example) that force emission is not important to performance of the task, but an ability to accurately perform a dynamic manipulation is. Consulting the Precise Hand

10.3 RECOMMENDATIONS (Continued)

Movement Task data bank, he could determine the proper restraint to recommend for task performance, the proper simulation technique to use for astronaut training, etc. He could even trade-off the time savings that might result from modifying an EVA task design to permit its performance in an IVA mode vs. the potential equipment ramifications of such a redesign.

The work reported in this document confirms the existence of a potential to satisfy the M508 program objectives. Flight performance of this experiment in the near future will capitalize on this potential and provide significant knowledge on the problems of human performance in zero-gravity.